Potato cannon for sub-caliber shooting ("long distance vandalism"), version 2023.29

Following this recipe is probably illegal.

- this is not a weapon, just a tool for vandalism - inaccurate and clumsy

- **when searching**, protect anonymity (TOR, I2P, foreign VPN)

- **when buying, your purchase can identify you** (many people need stuff, but few need all this stuff), also **when paying, your payment can identify you**: pay in cash, divide purchases into parts, **leave your phone home,** buy from different places at diverse times, **leave time between purchase and use**

- **when building, keep things clean,** put disposable material beneath the building place, wear working gloves (thin latex gloves can leave fingerprints, nitrile gloves for mechanics are better), wear a surgical mask, avoid hair or fingerprints under tape or glue, avoid contaminating your household with powders

- flammable gases are dangerous, if you mix them wrong, mixtures can detonate: wear protective glasses and earmuffs, have no distractions, be sure of measured amounts, if you feel static electricity, stop work and discharge yourself

- **acetylene byproduct phosphine is very toxic**, only work with carbide outdoors, **acetylene can decompose without oxygen** from heat, pressure or shock, avoid transporting in hot vehicles with windows closed

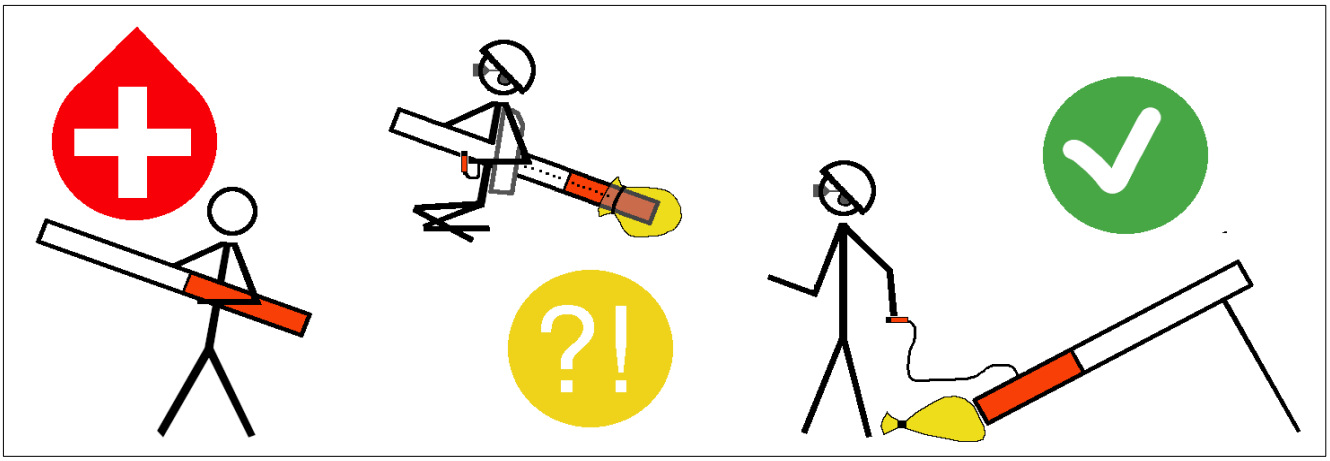
- **test everything**, shoot inert objects at a testing site first

- **when shooting**, wear protection: a thick scarf to protect your neck, a thick coat with a hood over your head, protective glasses and earmuffs under the hood, strong gloves (or use remote triggering)

- **when shooting armed projectiles**: arm the projectile first, fill it later; if a thermite charge accidentally fires, you don't want flammable liquid to be present

- **have a fire extinquisher,** 1 kg of ABC powder can save you from 100 tons of trouble

Drawing: horrible, doubtful and good work methods. Note: soft ground or sandbag!



In a state that started war, vandalizing state property could put you in danger. To avoid exposing yourself, it must be possible to vandalize from distance. Tools must be cheap enough to burn after using.

The simplest gun stand: a spade or digging fork. Above: an adjustable gun stand of 2.5 x 5 cm wood. It has a horizontal piece of 102 cm, holes 5 cm from ends. Diagonal pieces: 150 cm, holes start 15 cm from top, 15 holes with 5 cm intervals, bottom linkage holes

are 10 cm from bottom. Linkages are made of M8 bolts with wide washers and locking nuts. Holes are drilled with a 9 mm drill.

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Chapter 1: introduction

Typical guns have two zones: a **chamber** for propellant and a **barrel** where the projectile accelerates. These can be the same material or different. The chamber is where maximum pressure happens - it must be strong. For potato guns, practise shows that the ratio of chamber C and barrel B volumes should be 0.6 - 0.8. This is not an absolute rule. Example of C/B: (chamber length + hollow sabot length) / (barrel length + hollow sabot length). Numerically maybe (50 + 11) / (100 + 11) = 61 / 111 = 0.55 - close to reasonable.

Most potato guns are made of **polypropylene** (PP) or **polyvinyl chloride** (PVC) wastewater pipe. Particularly interesting are **110 mm pipes**, because standard food cans (850 ml and 1250 ml) have a matching diameter. It is hard to imagine a country banning wastewater pipes and food cans.

PP pipes are grey, a bit flexible and have a wall thickness of 2.7 mm. They are used to conduct wastewater in buildings. Tensile (pulling) strength varies from 19.7 to 80 MPa. Some stores sell **PPC (polypropylene copolymer)** pipes as "sound absorbing pipes". They are blue and have a multilayer 3.4 mm wall: really good. An example tensile strength is ~30 MPa. They have more resistance to impact and cracks.

PVC pipes are orange, made of **UPVC** (unplasticized PVC). They are stiff and have a wall thickness of 3.2 mm (at 110 mm). They are used to conduct wastewater in ground. Tensile strength is 41 MPa.

Good PP is superior to PVC - especially because PVC is brittle at room temperature, but PP only becomes brittle in frost. The best combination is probably a PPC chamber and a PP barrel, but **other features (tape wrapping, steel inner lining) add more safety than the best plastic.**

If you can, **please install a chamber lining + inner endcap of food cans**: the tensile strength of steel is far above plastic (250-2600 MPa). For big propellant charges or shooting from hard pavement, consider a 110 mm (2.45 L) fire extinguisher as a chamber bottom. Wrap the whole chamber in fragment-catching fiber tape.

Gun configurations: many configurations are possible. This manual focuses on 0.5 m chambers and 1 m barrels, allowing cheap guns that shoot manually ignited projectiles (with 1 m stems). Examples:

Parts	Chamber	Barrel	Lining	Wrap	Role
2	0.5 m	1 m	advised	advised	**more transportable**
1	0.5 m	1 m	advised	advised	**more accurate**
2	0.5 m	0.5 m	required	required	**covert, kinetic only**
1	0.5 m	0.5 m	required	required	**compact, kinetic only**
extinguisher + 2	0.5 + X m	1 m	required	required	**hard surface / big charge kinetics**
2	2 m	2 m	required	required	**puncturing 10+ mm steel**

Propellant: acetylene (C2H2) is the best. It is made by reacting **calcium carbide with water.** Hot gas is dried by passing through toilet paper, then thermally stabilized by passing through metal scrap. Productivity is around 295..300 L / kg. Alternative propellants exist.

Acetylene production should ONLY happen outdoors! Impurities in carbide give phosphine as a byproduct. Phosphine is highly toxic!

Ammunition: this gun can shoot "sticks and stones". Practical projectiles include "arrows" made of 32 or 40 mm wastewater pipe (manually or electrically ignited), fire bottles with a 40 mm PP stem, a single steel flechette, metal balls, stone pebbles, bottles, jars of paint.

Projectile mass: recommended "slow" projectile mass is around 1000 g. Projectiles down to 850 g (maybe even less) can use manual ignition: a gasoline rag with storm matches. Cover 2/3 of your storm matches with aluminum tape.

Sabots: to shoot subcaliber items from a 110 mm gun, you need sabots: 850 ml food cans. To make them resilient and match them to projectiles, you need PP pipe caps (32,40,50,70 mm) and packing foam. To make **front holders** which hold an arrow straight, you need styrofoam pipe shells, sponge or foam.

Stand: a triangular wooden stand is optimal. Alternatives: **spade, digging fork, telescopic mop**.

Logistics: one person can carry the gun and supplies for 2..3 shots. Carrying it loaded is impossible (gas escapes). Carrying it "ready to load" is possible with adaptations. Stems and arrows can be transported in the barrel. Acetylene can be made anywhere if water stays liquid. Water can be kept liquid in mild frost. Acetylene is dosed into the chamber from logistical "condom bottles" (soda bottles with a conical nozzle and a gas storage condom inside).

Uncertainties: gas density depends on temperature. As the chamber heats from shots, gas density changes. Air is like lottery: hot/cold, dry/moist, CO2 and water from previous shots. When propellant is diluted in air, timing matters. To dilute faster, a brushless fan is used. For more precision, always shoot on the same second after gas injection. Regardless, **this gun is not precise!**

If propellant detonates (gets a supersonic flame front) the chamber will burst. **Wear protective glasses, earmuffs or earplugs, a scarf on your neck, thick clothes with a hood, working gloves. Prefer long-wire triggers. Do not shoot from hand!** Recoil can break bones, cut and bruise. A bursting gun can blind, wound or kill. Sprayed gasoline can set you on fire. Even for one shot, a plastic chamber should be wrapped in tape. For many shots, I recommend a metal lining.

If you are the kamikaze who holds the gun despite warnings: only hold the barrel, never hold the chamber! If the chamber explodes, you are not embracing it. Put the back of the gun against soft ground or a sandbag. Dress like a cosmonaut. I hope luck favours you.

Wrap the chamber in tape. Bottom layer should be inelastic (to prevent the gun from ripping) use fiber-reinforced transparent packing tape. Top layer should be elastic: use duct tape. When wrapping, hold tape tense, ensure that turns overlap.

Support the bottom of the gun with soft soil, dig if necessary. On hard surfaces, use a sandbag - you can put the end of the gun inside the sandbag and tie the bag mouth around the gun. If you lay a plastic chamber against hard pavement and shoot, your gun **breaks very soon.** If you must lay it against stone, use a 110 mm steel fire extinguisher as the bottom.

Chapter 2: the simplest guns

Simple guns use manually ignited projectiles. Fire is carried to target with gasoline-soaked towels. Storm matches relight fire if acceleration blows it out. Bottles are easy to make and carry more fuel. Arrows fly longer and puncture weak obstacles.

1: stem, 40 mm PP pipe, top and bottom wrapped with narrow duct tape to prevent splitting

2: bottle (narrow 0.5 L glass, scratch with cutting tool; narrow-necked 1 L plastic, leave 20% air)

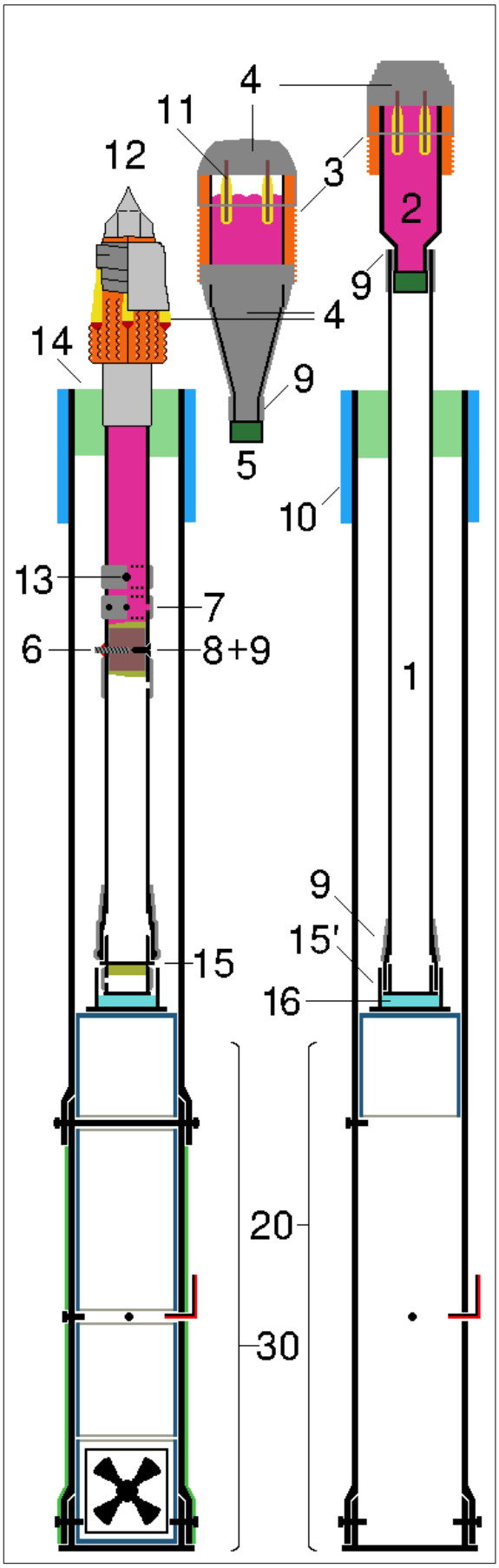
3: towel fire rag, fixed with narrow duct tape:
a) to nose of glass bottles (5..6 storm matches)
b) to nose and middle of plastic bottles (7..8 matches)
c) sliding on the stem of arrows (5..6 matches)

4: aluminum tape protects duct tape from fire, **covers 2/3 of storm matches** to prevent quick burning, and **with 2 layers, covers every part of a plastic bottle which is not under the rag** (protecting you) and covers the arrow tip for 30 cm

5: turnable cap (shooting opens pushable caps)
6: rag stopper (M5 threaded rod fixed with epoxy, stops the rag on its backslide, so fire is present above the **6 x 4 mm ejection holes (7)**, covered with duct tape

8: center wall, consisting of **wooden plug** (35 mm round wood wrapped with wide tape to correct diameter, sealed on both sides with **thermal glue** injected via 4 mm hole, fixed via **6 x 4 mm holes with 6 screws (3.5 mm x 15 mm)**

9: cover these areas with narrow duct tape
10: wet towel, recommended during practise
11: storm matches
12: cast iron cap with exterior thread for steel plumbing (or similar item), 1 inch suits 40 mm, 3/4 suits 32 mm
13: fill hole, 6 mm
14: front holder from styrofoam 40 mm pipe shells



15: double cap, 2 x 40 mm, rear cap with 2 x 4 mm holes, thermal glue injected, rear rim cut off
15': single cap with modified pipe (seal compartment removed) tolerating more acceleration

16: shock absorber (stiff bubble foam)

20: burner gun, cheap, 1 shot, more if lucky
30: heavy gun, chamber lined + wrapped, with fan

Chapter 3: about delivering fire

Shooting solid objects is easy: make a sabot, make a holder on the sabot, put something into the holder, cover with paper, fix with a rubber band, load and shoot.

Often, solid objects work. A repressive office without windows is ineffective. A vehicle without windows is slow. But sometimes, liquids are needed:

- to burn something (or deform with heat)
- to paint / corrode / etch something
- to cause a fireball and shock wave

This manual focuses on fire delivery because fire delivery is difficult. Fire is not always the best tool. Using fire makes the gun bigger and you slower.

The four ways (photo: left to right):

1. Electrically ignited arrows with a cast iron nose

These fly the longest. They can break through weak obstacles. A thermite charge bursts them with a fireball and shock wave (it could be lethal, take care). They must be carried unfilled for safety. Bad construction or unlucky landing causes failure. Slow to make. You need time and cover to prepare for launch. Risk of leaving evidence.

2. Manually ignited arrows with a cast iron nose

These fly reasonably. They can break through weak obstacles. They are much safer, can be carried full (when made with fuel-proof glue and tape). Not 100% reliable, but close. Medium speed making, superfast shooting.

3. Glass fire bottles

These fly shorter. Glass adds inert weight. Fully reliable against hard surfaces. Can be stored full. Unlikely to break through obstacles. Superfast to make and shoot.

4. Plastic fire bottles

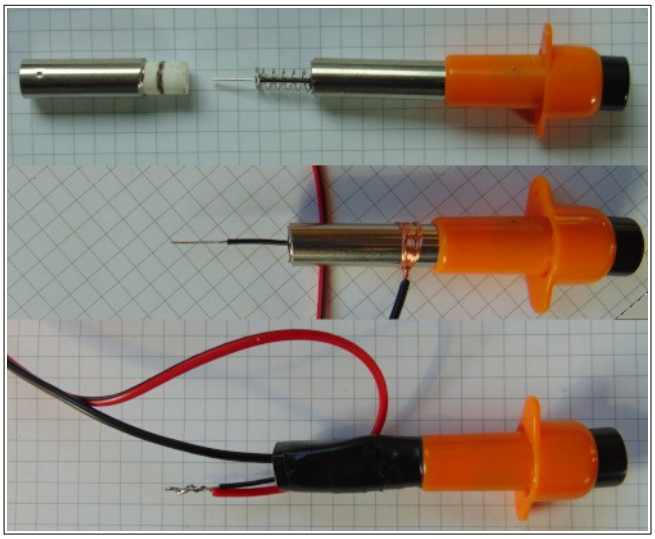
These fly shorter, but deliver maximum fuel. Fully reliable against soft surfaces, except thick mud and snow. They can be stored full. Unlikely to break through obstacles. Fast to make, superfast to shoot.

Chapter 4: piezoelectric triggers

The "trigger" is a piezo igniter. It can take many forms: some contain gas, others don't. My favourite type has 2..3 meters of the thinnest speaker wire connected to a no-gas piezo igniter. Everything is safer if you stand away from the gun. It even lets you work alone with manually lit projectiles - you hold a gas igniter in one hand, the trigger in your other hand.

The metal shell of the piezo has been sawed to half length. One speaker wire has been wrapped around the remaining shell, the other connected to the center wire of the piezo. If you make it too long, the wire has capacitance and things won't work. Test thoroughly (10 pushes must give 10 sparks).

Photos: making the igniter, permanent "spark plug" with tape + M8 wide washer



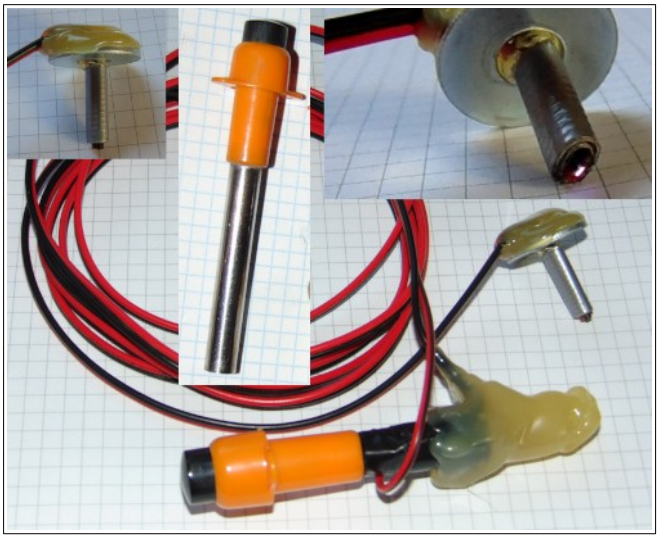
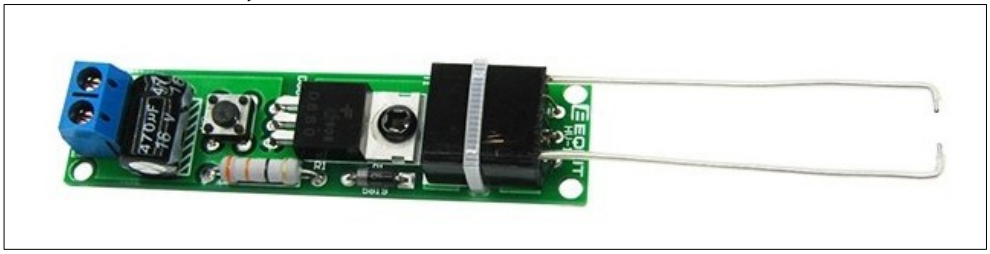


Photo: long-necked piezo igniter with gas (also good for igniting projectiles)

Photo: electronic arc generator from China (unreliable, avoid unless you need remote control)

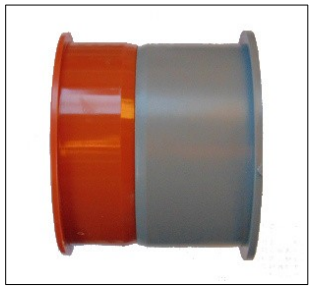


Chapter 5: making the gun

Tolerances and defects: internal diameters vary as much as 1 mm, guns need sabots tuned to their diameter. Most factories make pipes with narrowing ends. You can detect this by making a test sabot that barely fits into the pipe. If it starts sliding freely after passage, your pipe is conical. That is OK for chambers, but not barrels. If your barrel is conical, cut off 1 electrical tape width from the tip. Use a disc cutter, hacksaw or hot knife, clean the cut by filing or sanding. Alternatively grid the inside of the tip.

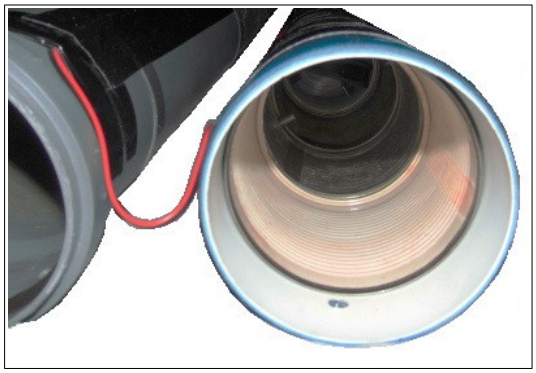
Making bolt holes: the chamber and barrel have similar rear bolt holes (chamber has 4, barrel has 2 holes). Put an M8 wide washer against the seal rim. With a pencil, draw a ring inside. Make a pilot hole (3 mm drill), then the main hole (8 mm drill, play a little to make the hole bigger). Alternatively, push a hole with a hot bolt (plastic ruins soldering iron tips).

Finding the opposite side: at bolt holes, pipe circumference is 37 cm, thus 18.5 cm = 180 degrees, 9.25 cm = 90 degrees.



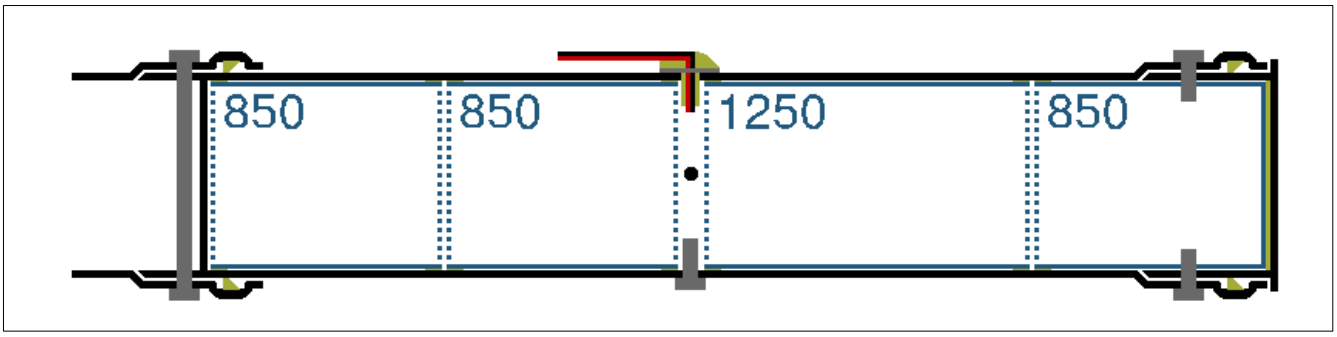
Choose the longest caps. PVC and PP caps are interchangeable. See the photo: orange PVC cap is too short, grey PP cap is nice.

Removing the seal: during this stage of work, you must repeatedly fit the bottom cap. For easy work, remove the seal from the pipe. Note the direction so you can put it back - the conical "opening" faces outside.

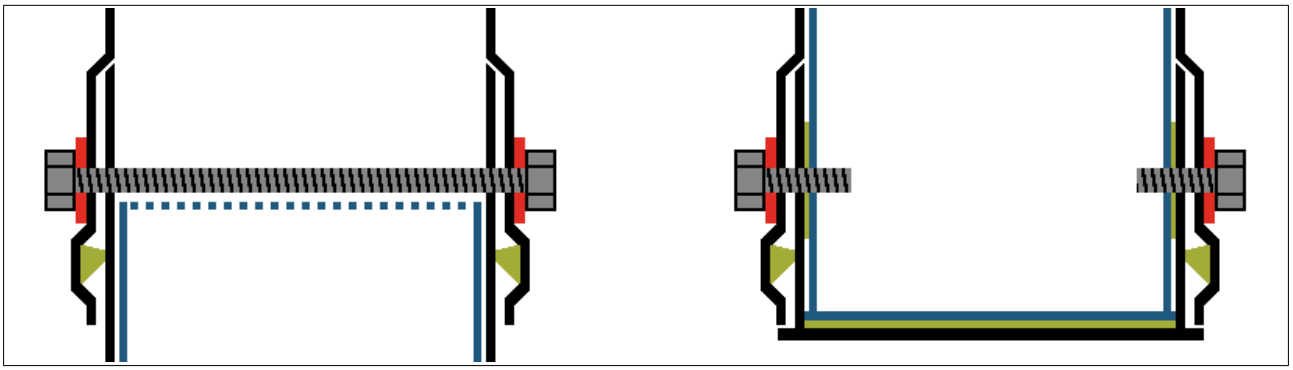


Installing chamber lining: steel lining made of food cans weighs little, but prevents dangerous gun bursting accidents. Find 850 ml fruit cans or 1250 ml dog food cans, measure how high they extend. Protecting the bottom of the chamber is more important - the top is held by the barrel. Open the cans, tape to correct caliber, test inserting into the pipe. Leave 8 mm reserve space for the gas injection and ignition holes.

Drawing: chamber with bolt holes (bottom), injection, protector bolt and igniter holes (center) and projectile stop holes (front). Steel cans depicted in blue.



Detailed drawing: center and bottom of the gun

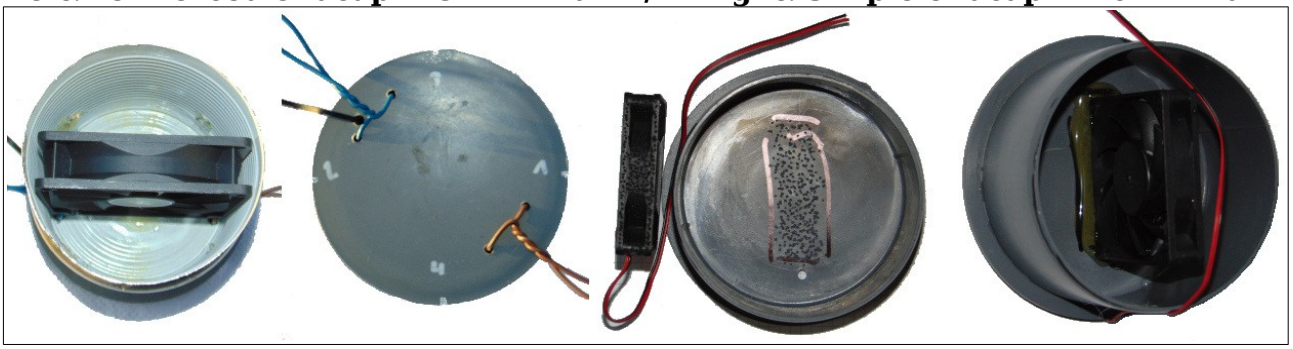


Preparing the endcap: bottom caps are a weak point. A flat surface encountering pressure will break quicker. If your chamber uses steel cans for lining, you can safely make a steel inner endcap (for a plastic chamber, do not reinforce the cap: it breaks to protect you).

Drill glue injection holes to the sides of plastic. Drill an air hole in the bottom of the metal can. Roughen both plastic and metal, heat with hair dryer, **use much thermal glue** (you can heat glue sticks directly with a hair dryer), push inner cap into outer cap. Seal the gap with a separate line of glue, so gas cannot get between the inner and outer cap.

Photo: making a reinforced end cap

Left: reinforced endcap + 92 mm fan / Right: simple endcap + 70 mm fan



Installing a mixing fan: install the fan in the bottom cap. This protects it from getting ripped by gas and allows easy replacement. **Mark hole positions, make holes, fix with wire, cable ties or glue.** Only use brushless fans (brushed motors make sparks), most fans are brushless. Ordinary (not PWM) 92 x 92 x 20 mm 12 V fans are suitable.

Use a 9V fan battery, cheaper than a 3S lithium battery. If the fan doesn't fit into the steel can, cut the rim of the can or use 80 x 80 mm. **Making one shot does not require a fan: wait 60 seconds and gases will mix.**

Installing the endcap: test without the seal first. Push the cap onto the chamber end. Drill holes through existing holes, push M8 bolts (length 2 cm) into holes . Double-check, mark a matching position, add the seal and close with necessary force. Tape bolts over to keep them during shots or transport. In hurry, you can connect the endcap with U-turns of tape, then fix the U-turns with a ring of tape.

Connecting the fan: PC fans have 3 wires. Black = ground, red = plus, yellow = not needed. If all wires are black: white-striped black is ground (find "+" by testing). If you use a drone battery, tin the ends of the fan wires and push them into the balancing connector. If you use a 9V battery, dismantle an old device which uses a 9V battery (e.g. smoke sensor, toy) or buy a connector. For long-term use, deposit thermal glue where wires and cable ties pass through plastic (jets of hot gas erode it). Wires can be soldered or turned around each other to connect them. Electrical stores also sell quick connectors which close with a click.

Installing the barrel: if you have bolt holes, note their positions and align them. If not, push the barrel on the chamber until the end, drill chamber holes through barrel holes. Push a **projectile stop** made of M8 threaded rod (**length 13.5 cm**) through holes, put M8 wide washers and nuts onto it. Tighten with fingers, don't deform the pipe. The projectile stop prevents a projectile from falling to the bottom. It also keeps the gun together during shots. If seals are too strong, use dish washing liquid as grease.

Photo: triple-wrapped PPC chamber is complete. Note the M8 thread drill: the fill hole is threaded and the protector bolt hole also (the bolt protects the igniter from the chamber lining cans). Closing the fill hole with a bolt gives a little performance and lets you to wait longer before shooting. (For a "burner gun", don't bother to make these conveniences. The same hole can work as the fill and ignition hole. The protection bolt is needed, however.)

Photo: left to right: sandbag, fan battery, inclinometer, laser aimer, piezo igniter, projectile igniter.

SHORTCUTS

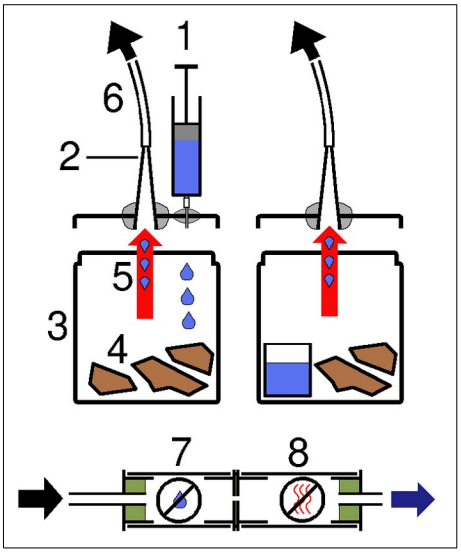
- if the place has soft soil, you don't need a sandbag
- **for one shot**, you don't need a chamber fan, wait for 60 s, gas mixes naturally
- **for a one-shot disposable gun**, supporting your gun with soft ground, using a long-wire trigger for safety, using fresh pipe (no prior shots), you can use minimal wrapping and no chamber lining, plastic rarely breaks on the first time
- if the target is big and you use scatter-shot, or everything is flammable there, you don't need a laser

Chapter 6: making acetylene

The cheapest and most powerful propellant is acetylene. It ignites in a wide range of mixtures, air is enough to oxidize it. It is made from **calcium carbide and water**. Acetylene can decompose without air: keep it from shock, pressure or temperature. Store away from fuels. If you transport by car, keep in the trunk. If you can't, keep some windows partly open, ideally wear earplugs. Don't leave in sunshine. I have made multiple rides of 1 hour in evening and nothing happened, but bottles leaked (could be smelled) and lost 10% of gas.

Only make acetylene outdoors! Technical and "pest control" carbide has impurities which produce **phosphine, a highly poisonous gas! You can smell phosphine at 0.3 parts per million. At 50 ppm, it is immediately dangerous to health and life. At 1000 parts per million, it has a 50% probability of causing death (LD50) with an exposure of 5 minutes. Keep carbide dry. Use only outdoors.**

Reaction produces hot gas and steam. Since shooting power is determined by molecule counts, but the number of molecules in a volume depends on temperature and pressure, you must cool and dry the output gas. Use a "reactor" like this:



1: 20 ml medical syringe, needle glued to lid with heat-proof metal-filled expoxy (sand glued surfaces); when you cut needles they tend to close, with sandpaper they open again

2: construction glue nozzle, glue to lid with heat-proof metal-filled epoxy (sand glued surfaces)

3 - glass jar, ideally with an easy-open lid
4 - calcium carbide
5 - acetylene and steam
6 - flexible hose (4..6 mm)
7 - dryer (32 mm pipe joiner filled with toilet paper)
8 - cooler (32 mm pipe joiner filled with metal)

Reaction is controlled by adding water or tilting / shaking.

Don't overheat, glue could loosen! Wear protective glasses, jar could explode!

Discard the first 2 bottles of gas: they contain a mix of acetylene and air. With 20 ml of water, you can make 2+ liters of C2H2.

Change toilet paper (7) every time you start the reactor. For cooling (8), I use pieces of aluminum welding rods, but any metal works.

Chapter 7: logistical "condom bottles" for gas

To shoot several times before escape, you must load propellant reliably and fast. A logistical container could be anything from condoms to big syringes or juice bags. My preferred solution is **condom bottles**, where a soda bottle **determines volume and protects a condom.**

For small volumes, risk of condom breaks is low: **at 500 ml, failure rate should be zero. Condoms can break from cold.** Ordinary condoms work up to 750 ml, beyond that special condoms are needed. I have successfully used "Mister Size" 64 mm and 67 mm at volumes up to 1.3 liters and temperatures down to -15 C, leaving them in cold for 12 hours while empty, 1 hour while full. If you vandalize in harsh cold, consider PU (polyurethane) condoms or carry propellant in an insulated bag with a bottle of warm water. If a condom repeatedly breaks, you could have a bad bottle (some bottles have sharp bits inside).

Making logistical bottles:

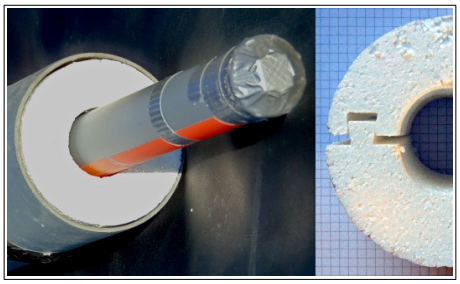
- get a sport drink bottle with a **push-pull cap (see photo)**
- get a conical extruder nozzle for a construction glue gun
- unless your bottle is 500 ml, also get a 500 ml soda bottle (Sprite and Pepsi seem to have good shape)
- optional: file off the widening rim of the cap
- optional: sand the exterior of the nozzle
- cut the nozzle where its diameter equals the cap
- put them together and wrap flexible electrical tape around them
- you can also join them with a heat-shrink tube that has glue inside (for electronics repair)
- make a little (3 mm) hole into the bottom of the bottle to equalize pressure
- unroll the condom, twist it so it becomes thin and compact
- guide the condom into the bottle, leave its rim outside, install the bottle cap (not too strong)
- paint around the hole with a black marker to see it in field conditions

Alternatively, 0.5 L juice bags are handy, many types of taps can be fixed to a bottle somehow.

Chapter 8: common elements: front holders, tail caps

All projectiles based on plastic pipe share common design elements:

8.1 Front holders



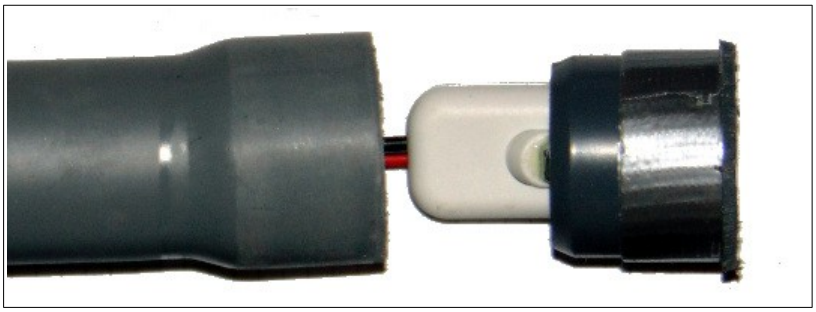
To shoot straight, projectiles must sit straight. A front holder can be manufactured from **sponge, packing foam or styrofoam.** The best: **styrofoam pipe shells made of two interlocking halves**. They withstand moving the gun, but I don't recommend walking with a loaded gun. If you don't want precision, a sponge circle (or semicircle) with a hole is OK.

8.2 Tail caps

Powerful shots can break projectile stems. To reduce risk, we use packing foam as a shock absorber.

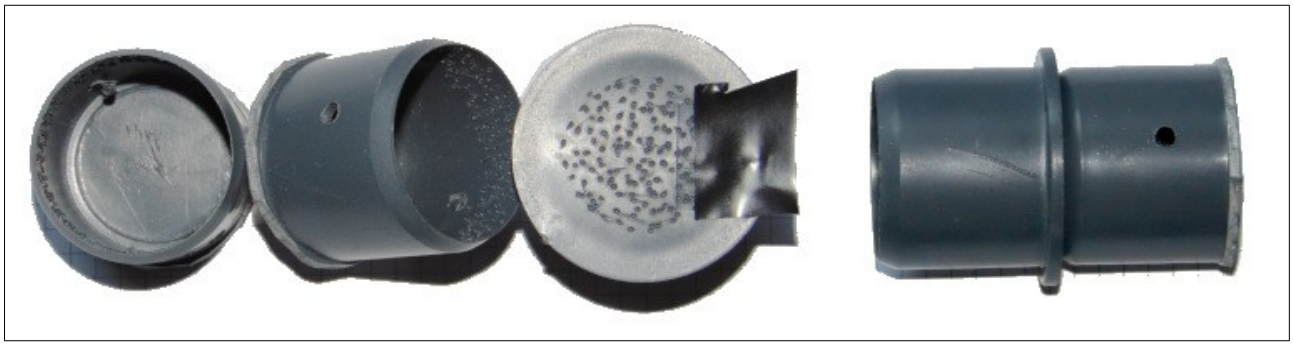
Two methods exist to brace the projectile against impact:

- Single cap (tolerates high acceleration)



Cut the seal compartment off the 40 mm pipe. You are left with a wide tail which fits perfectly into a 50 mm pipe cap (clearance < 1 mm). Using metal scizzors, pincers or grinding, bring the rim of the cap down to the same diameter (or a bit smaller). Wrap tape around the tail cap until it goes into the pipe with resistance and comes out with a "pop" sound heard on opening wine bottles.

- Double cap (tolerates medium acceleration)



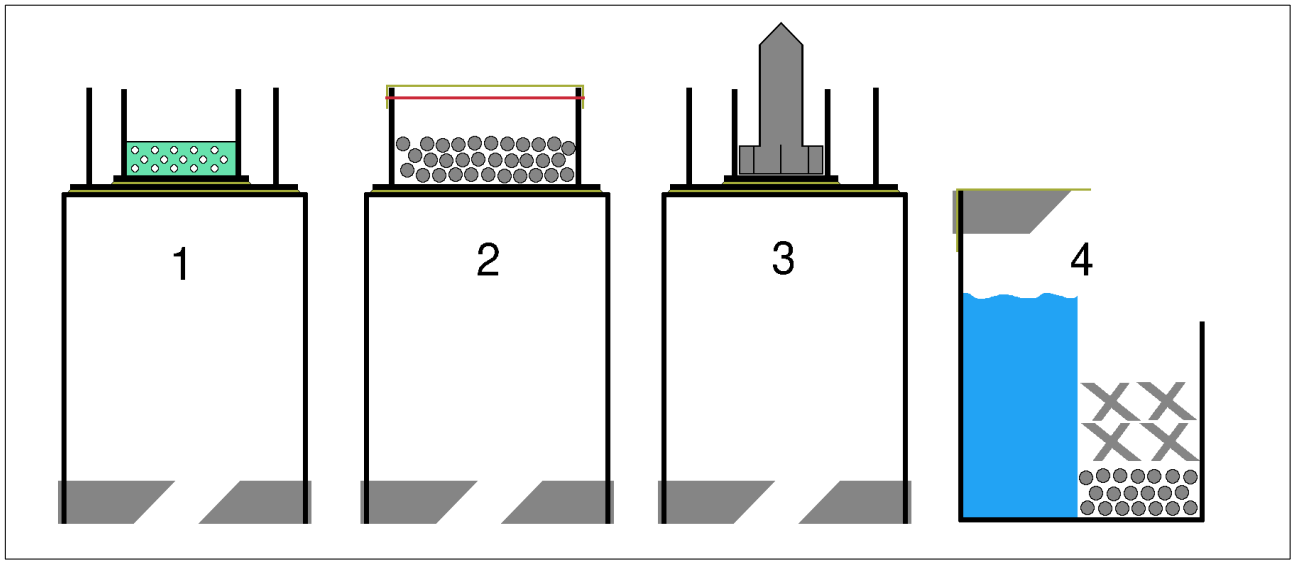
Take 2 pcs of 40 mm PP pipe caps: inner and outer. Drill a 4 mm glue injection hole and air escape hole into the outer cap. Roughen its interior surface to a distance of 1 cm from the open end. Roughen the back surface of the inner cap. Heat up a glue gun, fit the caps together, squeeze plentiful glue (e.g. 5 pushes with an 11 mm glue stick) into the outer cap. Keep vertically under something heavy until glue cools.

9. Sabots

In old times, artillerists used wooden pieces ("sabots") to fit a cannonball into a cannon. Tanks can shoot fast kinetic "arrows" at each other, which are below the diameter of their gun. Such arrows are packed in containers that fall off when leaving the barrel: discarding sabots. Physicists might say "a discarding sabot is a piston that leaves after work" - it lets you accelerate a small object to high velocity using a low-pressure gun.

Our sabot system is made around **850 ml fruit cans**. To match diameters, narrow (2 cm) duct tape is wrapped around the open end. **The sabot must fall freely but slowly in the pipe**.

Drawing: many types of sabots can be improvised



1: for arrows and bottles, double top 70 + 50 mm PP pipe caps, bubble foam shock absorber
2: for horizontal scattering shot (anti-window), tape or rubber band retaining a paper cover
3: for a flechette (to puncture thin metal sheet), double top 70 + 40 mm (M22) or 70 + 32 mm (M18)
4: reverse sabot with plastic cover (inert liquids), open sabot for upward scattering shot

If you shoot projectiles (1..3), the sabot has its open end backward, and the tailward rim is taped. **If you shoot solids or inert liquids in bulk (4**) at very short range, you can reverse the sabot (for liquids, close the front end with plastic, for solids, close with paper). Don't shoot flammable liquids this way, it is dangerous and not effective.

If you shoot objects which need high velocity (pebbles, metal balls) you can increase their velocity by decreasing their mass - put them into a small plastic holder on the sabot. Lead is the densest practical material, and flies longest - but on collision with hard objects, lead is soft. Steel is less dense, but harder. Stone is even less dense, but hardest. **Take great care to avoid overshooting or missing the structure you aim at - people could be somewhere down range!**

Never shoot with too short sabots, e.g. fish cans. They could jam in the barrel.

Recipe for arrow and bottle sabots:

- take a can, remove labels, roughen the bottom on the outside (coarse sandpaper / disc grinder)
- take a 70 mm pipe cap, roughen its bottom both inside and outside (file / disc grinder / hot object)
- take a 50 mm pipe cap, roughen the bottom on the outside (file / disc grinder / hot object)
- make 4 pcs of 4 mm holes into the 50 mm pipe cap (prevent vacuum during projectile separation)

Take a hot-melt glue gun (bigger is better). Pre-heat the can with a hair dryer, apply all the thermal glue your gun can supply (don't press hard, glue guns break easy). If your gun cannot supply enough glue, keep the glue heated with a hair dryer while the glue gun warms again. When you have enough glue, press down the 70 mm pipe cap. Wait for your glue gun to warm up. Using similar methods, glue the 50 mm pipe cap. Cut a ring of dense (small-bubbled) packing foam, fit it inside.

Photo: making a sabot, complete sabots with 50 mm PP pipe cap inside a 70 mm PP pipe cap.
Note the small holes (4 mm) at the base of the inner cap - to release the arrow easier.

Recipe for flechette sabots:

- don't use a shock absorber, the sabot will be destroyed anyway
- use a stifferning plate made of a 70 mm pipe cap (edge trimmed to height of 1 cm)
- inside it, for a 22 mm flechette, use a 40 mm pipe cap
- inside it, for an 18 mm flechette, use a 32 mm pipe cap

Photo: flechette sabot (the flechette must go in with minimal force, but not fall out)

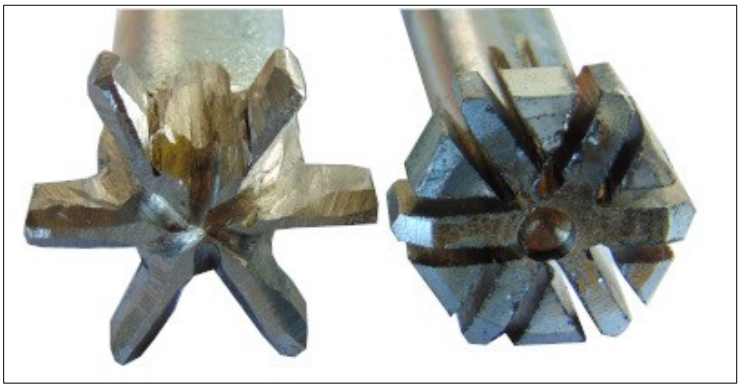
10. Flechettes

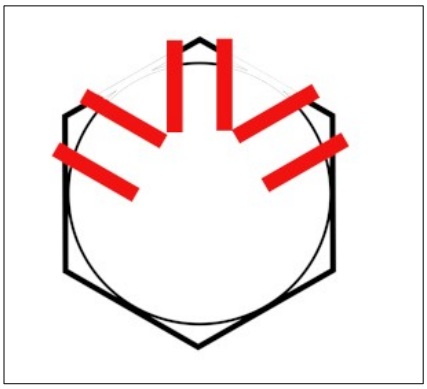
Photo 1: M18 bolt as 103 g flechette, M22 bolt as 205 g flechette.

A flechette is like a bullet, but stabilized by fins. Due to length, flechettes penetrate material better than bullets. Flechettes can be shot at full charge (558 ml of C2H2, more with bigger chambers).

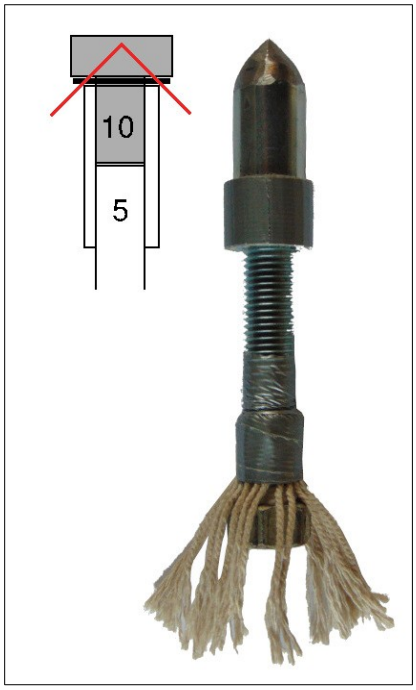
CAUTION: never shoot a flechette unless you know what stops it! It could accidentally hit a person far away - and wound or kill! I would only shoot them at a big things. I don't have range or ballistic data. Don't be too close, rebounding pieces can wound you. If you must be close, hide behind something - returning pieces aren't very fast.

If you use bolts, M18 fits into 32 mm pipe caps. M22 fits into 40 mm pipe caps. In both cases, use a 70 mm pipe cap as additional support to keep the base from bending during the shot. The bolt head becomes the tail fins. With some grinding, it fits inside the cap. The amount of cutting and grinding is big - it took me 2 hours. You need a disc cutter, a vise or clamp, cutting disks (beginners should use thick discs for safety) and personal protection equipment. **Photos: completed tail, making the tail, ideal cutting paths.**





10.B Composite flechettes



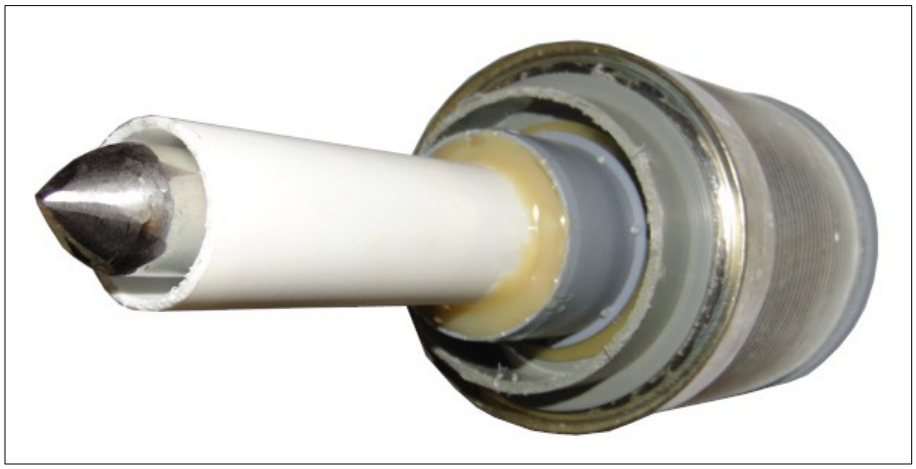
If you want maximum penetration, consider making a composite flechette. It costs more but uses nothing exotic. It weighs 290 g, can be made fast and requires less metalworking skill.

Tip: M16 bolt, hardness 10, length 3 cm.
Washer: hard bolts aren't threaded fully, use a washer to avoid a gap.
Round nut: surrounds the tip, distributes load and prevents fragmenting, corrects the center of mass. When cooled, wrap with tape to loosely fit inside a 32 mm plastic pipe.

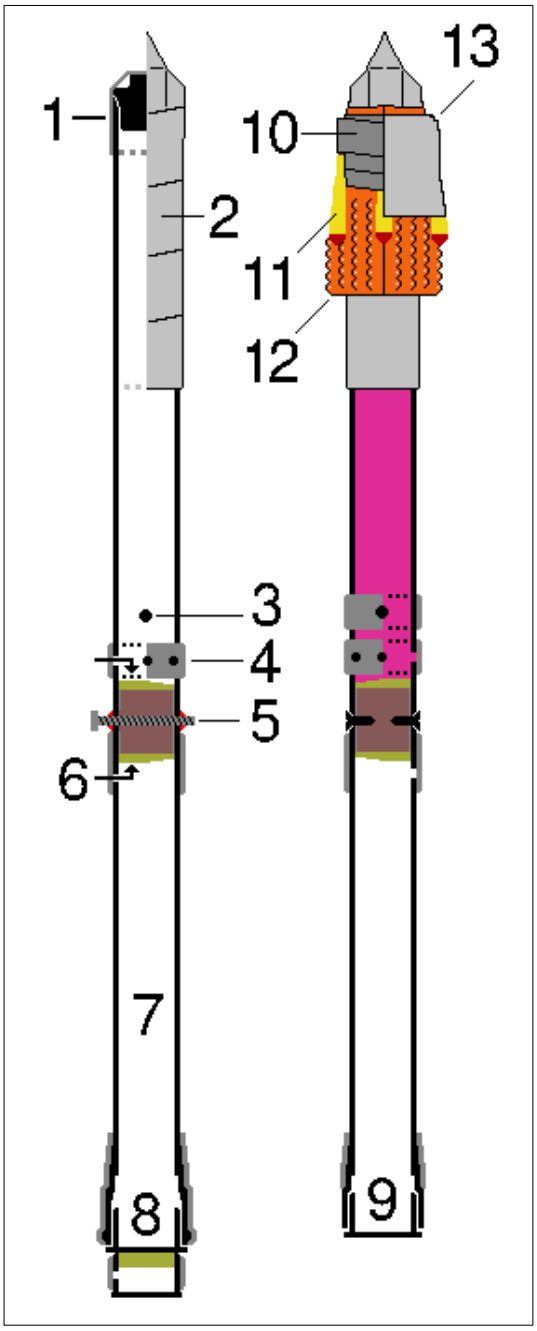
Tail: M16 threaded rod (11 cm). Soft metal, gives mass and corrects the center of air resistance with ~20 pieces of string.

Sharpening: install the components and sharpen with a disc grinder, cooling as required.

Hex nut: widens the tail for better support against the sabot.
Photo: composite flechette with a special sabot (32 mm plastic pipe glued into 50 mm pipe cap)



11. Fire arrows (manual ignition)



Main body: 40 mm x 1 m plastic pipe.
Empty mass ~550 g, launch mass (gasoline) ~850 g.
Liquid delivery volume: ~500 ml (wall at 50 cm).
Range: 110...140 m.
Longer range and smaller volume with 32 mm.

1: nose (1 inch cast iron cap for 40 mm, 3/4 inch for 32 mm), narrow duct tape tape aerodynamic cover

2: fire-resistant cover A (aluminum foil, aluminum tape with "candy wrap" type twisted tip)

3: fill hole (6 mm), tape over when filled

4: spray holes (6 x 4 mm), one is used for injecting glue

5: wooden plug (35 mm), diameter increased with wide electrical tape, 6 pcs of 4 mm holes, 4 pcs of 3.5 x 15 mm screws, 1 pcs of 4 x 60 mm bolt as **rag stopper** (fixed with glue)

6: glue injecting hole (4 mm)

7: main body of 40 mm or 32 mm PP wastewater pipe, reinforced with duct tape near tail (to avoid splitting)

8: double 40 mm cap, rear cap with 2 x 4 mm holes, thermal glue injected, backward rim cut off, reinforced with tape

9: 40 mm cap, rim trimmed, reinforced with tape

10: narrow duct tape holding the fire rag and storm matches (sliding the rag must require some force)

11: storm matches, 6 pcs
12: fire rag from a towel
13: fire-resistant cover B, aluminum tape

Aluminum tape must cover 2/3 of storm matches, ensuring they cannot catch fire from every point. They need to burn slow. Gasoline may be extinguished by the shot, storm matches re-light it when the arrow slows.

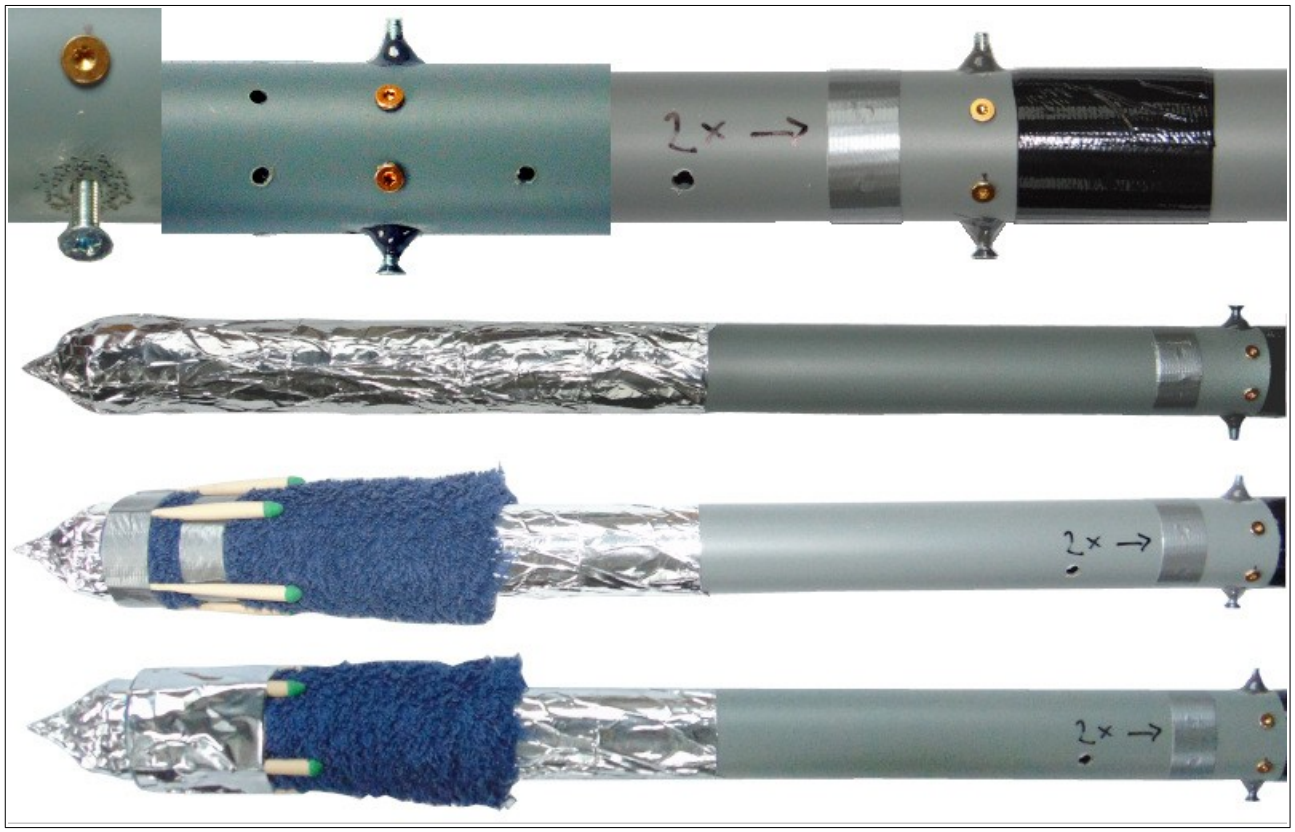
Routine:

- install in gun, aim

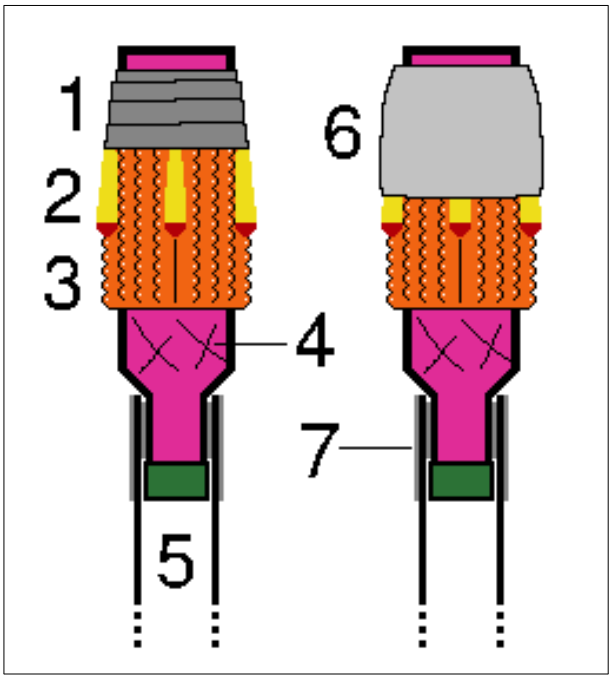
- add gasoline (~30 ml, it should not be dripping)
- inject gas
- ignite the fire rag
- shoot in 2..3 seconds (sooner if you see a match burn)

If launch fails: risk of fire! Piezo failure? Quickly push 3 more times! Have pre-made plans: do you burn the gun or attempt to extinguish? In either case, grab the gun and make a forward push to eject the bottle. When the bottle is on ground, you have ~10 seconds to act. Extinguish -> use sand or ABC powder. Burn -> retreat, do not handle. When it burns open and the plan is burning the gun - add the gun into fire, muzzle pointing away (acetylene is inside).

Photos: manually ignited arrow construction



12. Fire bottles (glass)



Stem: 40 mm x 1 m PP pipe.
Bottle: 500 ml oil bottle filled to maximum.
Full bottle without stem: 765 g.
Launch mass 1020 g.
Liquid delivery volume: ~510 ml.
Range: 80..100 m.

Long 500 ml oil bottles are used to sell salad oil, but also supplied empty to store home-made oils.

1: narrow duct tape holding the rag and matches
2: storm matches, 6 pcs
3: fire rag, towels have large surface area
4: scratches made with a glass cutter

Without scratches, I have seen a bottle fly 130 meters, land on soft ground and **not break!**

5: turnable cap, push-caps open during the shot

6: fire-resistant cover of aluminum tape (it needs to cover 2/3 of storm matches, ensuring they cannot catch fire from every point), storm matches must burn slow and re-light gasoline if flight has blown it out

7: tape, wrap it around the bottleneck, around the plastic pipe covering the bottleneck, and if possible, tape the bottle to the plastic stem

Routine:

- install in gun, aim
- add gasoline (~30 ml, it should not be dripping)
- inject gas
- light the gasoline
- shoot in 2..3 seconds (sooner if you see a match burn)

If launch fails: risk of fire!

Piezo failure? Push 3 more times! Have pre-made plans: do you burn the gun or attempt to extinguish? Grab the gun and make a forward push to eject the bottle. When the bottle is on ground, you have ~10 seconds to act. Extinguish -> use sand or ABC powder. Burn -> retreat, do not handle. If it burns open (it may not) and the plan is burning the gun, add the gun into fire, muzzle pointing away (acetylene is inside).

13. Fire bottles (plastic)

Stem: 40 mm x 1 m PP pipe.
Bottle: 1L plastic bottle with long neck.
Full bottle without stem: 765 g
Launch mass: 1030 g.
Liquid delivery volume: actual ~800 ml.
Range: 80..100 m.

Bottles like "Perrier" and "San Pellegrino" are the best. You need to leave 20% air so they reliably burn open.

First, wrap the bottleneck with at least 1 layer of duct tape (to give strength) and 2 layers of aluminum tape (to resist fire).

This avoids dangerous accidents where the bottleneck is already melting and you shoot, so a thermobaric fireball happens near you.

Take enough towel to cover most of the bottle. (Under the towel, fire doesn't burn and melting is delayed.) Tape it firmly with 2 bands of narrow duct tape - so it cannot come off.

Attach storm matches with narrow duct tape. Some matches are destroyed by the shot. At least one surviving match is enough to relight the projectile. I use 8 matches. Cover the forward part with aluminum tape (2/3 of matches must be covered). Also cover the band of duct tape with aluminum tape.

Fit the bottle to the stem by wrapping more tape near the bottlecap, fix it to the stem firmly with duct tape.

Routine:

- install in gun, aim
- add gasoline (~30 ml, it should not be dripping)
- inject gas
- light the gasoline
- shoot in 2 seconds (sooner if you see a match burn)

If launch fails: immediate risk of fire!

Piezo failure? Push 3 more times! Have pre-made plans: do you burn the gun or attempt to extinguish? Grab the gun and make a forward push to eject the bottle. When the

bottle is on ground, you have ~5 seconds to act. Extinguish -> use ABC powder. Burn -> retreat, do not handle. When it burns open and the plan is burning the gun - add the gun into fire, muzzle pointing away (acetylene is inside).

14. Fire arrows (electrical ignition)

This is dangerous. Accidents can be fatal. Only make these with great care for safety!

Empty mass 650 g, launch mass 960 g (with 20 mm x 20 cm thermite charge). The center of gravity must be ahead of the center of aerodynamic friction. The front 50% of the arrow contains the metal nose, battery, fuel and thermite stick. The rear 50% is mostly empty.

main body	40 mm wastewater pipe, 1 m
bottom cap	1 or 2 pcs of 40 mm pipe cap
nose cap	1 inch cast iron pipe cap (or improvise, e.g. wooden plug with tape rim)
power source, nose ballast	**high-current** 18650 battery glued into the nose cap
center wall	35 mm piece of wood / 32 mm pipe cap, edges trimmed / lots of glue
glue	hot-melt glue for most parts, epoxy for switch ballast and thermite charge
tape	electrical tape + duct tape
screws	6 pcs of 3.5 x 15 mm (at most 16 mm) wood screws
impact switch	lamp switch with 2 positions
switch ballast	sanded M6 nut (hard shots and surfaces) or M8 nut (soft surfaces) glued onto switch key with epoxy
wire	**1 mm2** (1.5 mm2 is OK) flexible copper cable, speaker cable is ideal, you need 2 wires of 1.5 m
connectors	screw terminal blocks for lamp wire, copper interior, ~8 mm step
ignition bridgewire	0.6 mm stainless steel wire (if you replace - test properly)
thermite charge body	20 cm of 2 cm electrical cable pipe
thermite charge sealant	toilet paper + thermal glue + fuel resistant epoxy
gypsum thermite	**by mass: 3 parts gypsum, 2 parts aluminum** by volume (depends on particle size): 1 gypsum : 1.65 serebryanka (AP1,AP2)
moderator	for a fuel payload, plentiful toilet paper (e.g. 4 meters) to limit dispersion and prevent thermobaric effect

Tools:
- hot-melt glue gun (bigger is better)
- drill, 4 and 6 mm drill bits (or avoid using wood: push holes into plastic with hot bolts)
- pincers for cutting and stripping cable
- small flat screw driver (for cable terminals)
- soldering iron, flux cored solder
- hair dryer

Tools for thermite:
- scale or weights to measure mass

- cups and spoons to measure volume and load
- plastic zip bags with double seals (to mix)
- funnel fitting into 20 mm cable pipe (to load)
- compacting rod, e.g. wooden pencil

* Here and every time: **if you want to keep flammable liquid in projectiles over 15 minutes, use solvent-resistant epoxy.** Only use epoxy (3-15 minute version) for the switch ballast. Only use solvent-resistant epoxy for the outer caps of the thermite stick.

14. Electric arrow sequence of use

14.1 Make a center wall
14.2 Install the center wall
14.3 Make a nose
14.4 Make a deceleration switch
14.5 Make a bridgewire
14.6 Make thermite
14.7 Test ignition
14.8 Make thermite charges
14.9 Add toilet paper + plan your safety precautions
14.10 Close and reinforce the tail
14.11 Arm the arrow
14.12 Fill with fuel, seal the fill hole
14.12 Load, shoot, escape

Parts:

1) one-inch cast iron pipe cap
2) high-current 18650 cell
3) positive wire to switch
4) return wire from switch, into thermite charge
5) negative wire into thermite charge
6) connector block

7) thermite charge (for study, replace with LED light): 20 cm x 20 mm cable pipe, toilet paper wads, thermal glue + epoxy caps, connector block, 0.6 mm stainless steel bridgewire

8) **wooden center wall**, fixed with 6 screws, side seals of tape, top and bottom seals of injected glue

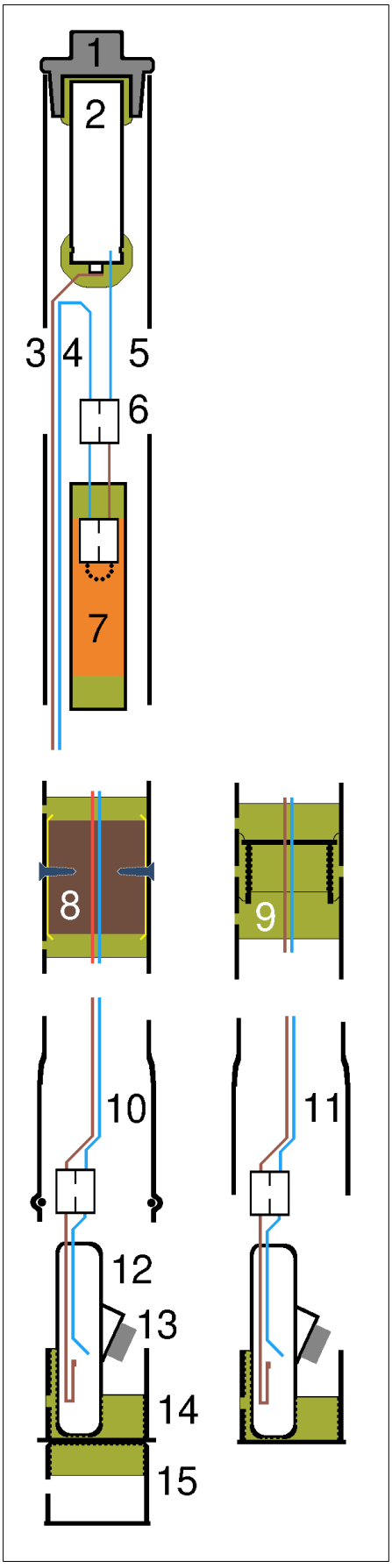
9) **plastic center wall** (32 mm pipe cap, rim trimmed off, sides roughened, filled with glue, sealed in place with glue)

10) low-acceleration tail (seal compartment can break)
11) high-acceleration tail (seal compartment sawed off)

12) lamp switch
13) switch ballast (M6 nut glued with epoxy, M8 for soft surfaces)
14) bottom cap A, holding the switch
15) bottom cap B, goes into sabot

16) fuel space, **add lightly compressed toilet paper to reduce risk of thermobaric events**

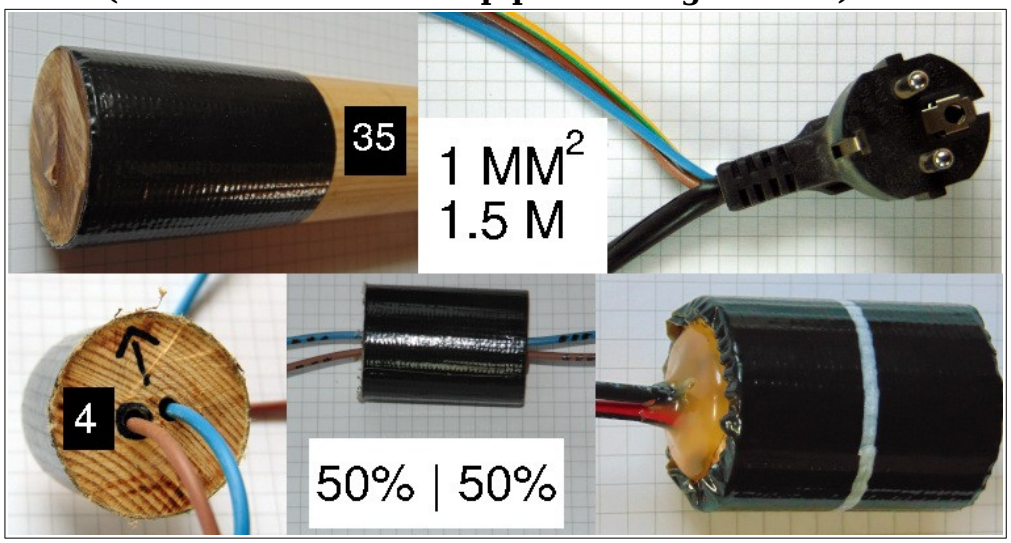
! all glued surfaces should be treated for better adhesion, metal by sanding, plastic by dotting with a hot tool / filing / scratching



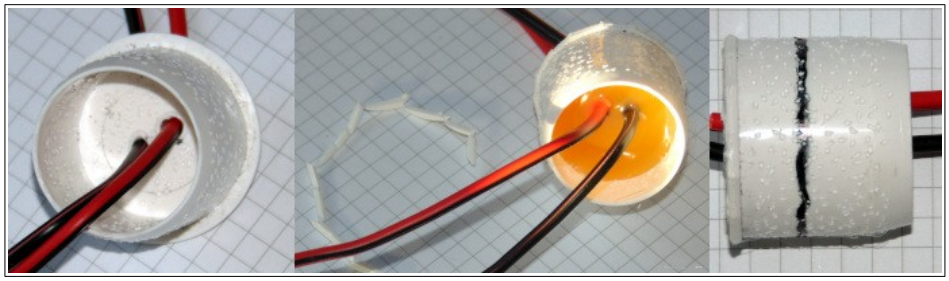
14.1 Make a center wall

Option A (better): **35 mm round wood**, 2 glue injection holes + 6 screw holes, tape, screws
Option B (no drilling): **32 mm PP pipe cap** (rim trimmed off), 2 + 6 glue injection holes, tape

Wood (must move inside the pipe with slight effort):



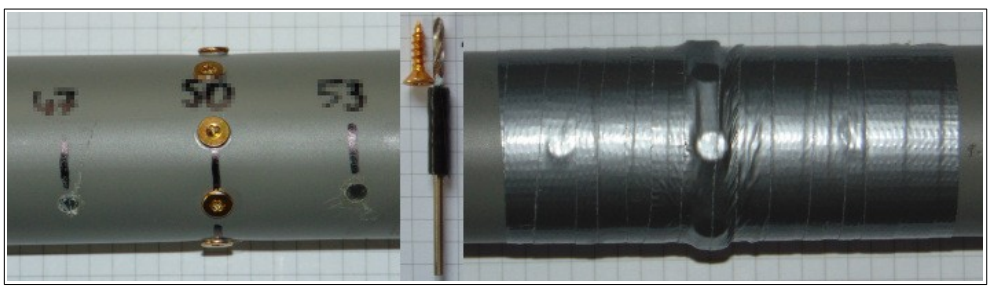
Plastic (if you don't have a drill), note the dotted surfaces for better adhesion):



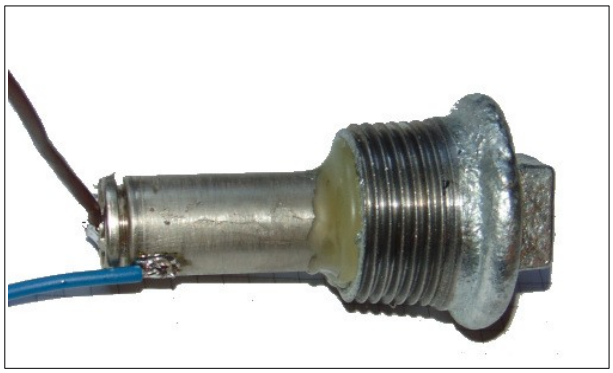
Wire: you need **1 mm2** thin stranded copper to conduct enough current. Audio cable is ideal, thicker wire works, but is harder to loop back inside a switch. If you build a return path with the secondary track of a switch (typical lamp switches have 2 tracks, one switchable and one always on), you can easily use 1.5 mm2 wire.

14.2 Install the center wall

Mark the 47, 50 and 53 cm points. Make a ring of 6 x 4 mm holes at 50, single 4 mm holes at 47 and 53. Push the center wall into its place with a stick, until you see the white line from holes. Wrap a 2.5 mm drill with tape to limit depth. Drill 6 shallow (limit the drill depth with tape) guide holes, install 6 pcs of 3.5 mm x 15 mm screws. Inject plentiful thermal glue (half of long 11 mm stick, wait until the glue gun re-warms) above and below the center wall, allowing glue to cool between this. Finally wrap everything with duct tape.



14.3 Make a nose



Strip an 18650 cell of plastic cover, sand off the serial numbers, scratch the places where you need to solder - deposit solder on the positive pole and the side of the casing (negative).

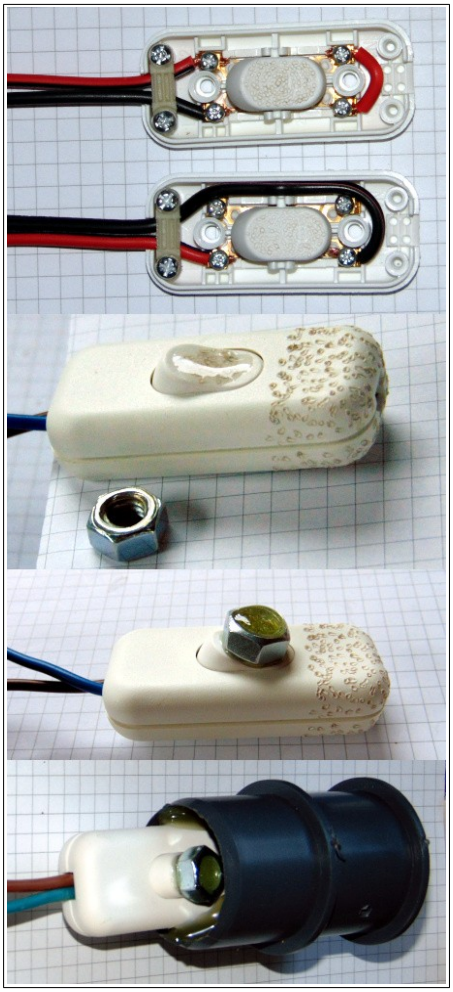
Take a 1-inch pipe cap, start warming a glue gun, meanwhile heat the pipe cap (no limit) and warm the battery (don't cook it) with a hair dryer.

When the glue gun is hot, deposit glue in the cap (approximately 7 pushes with an 11 mm glue stick) and push the battery in. You can cool the assembly under a tap with water.

Solder a red / brown wire going to your switch to the "+" pole. Solder a separate 25 cm black / blue wire to the "-" pole. To avoid short circuits, keep wires tips isolated.

To strengthen the assembly mechanically, cover the battery tip with glue.

14.4 Make a deceleration switch



On the tail side, install a 2-position lamp switch, so that **"ON" is forward.** The switch housing must stick to thermal glue during violent acceleration and impact. Dot the tail end of the switch with a hot metal object (e.g. spare tip of soldering iron).

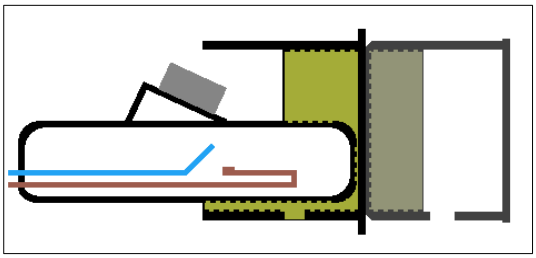
In a typical switch, the phase wire ("L") is switchable while the neutral wire ("N") is always connected through a second track. If your wire diameter allows returning in the switch, only use the switchable track. If your wire diameter is big, put a "bridge" at the tail end, receive the returning current via the parallel track. If the wire cannot be returned inside the switch, run it outside along the back.

Switch ballast: **M6** nuts (2.1 g) or M8 nuts (4.5 g). The ideal weight is between them (maybe M6 + fishing lead). For hard shots and hard landings, choose M6 (acceleration can destroy a switch). For soft shots and soft landings, consider M8.

The switch key needs excellent contact: sand the nut, dot the key with a hot metal object. Use epoxy glue. One droplet first (it tends to leak), wait and mix another droplet to fill the nut.

Check for defects, hitting a table with the switch must flip it. Holding the switch by a wire of 20 cm and making a striking movement, centrifugal force must flip the switch.

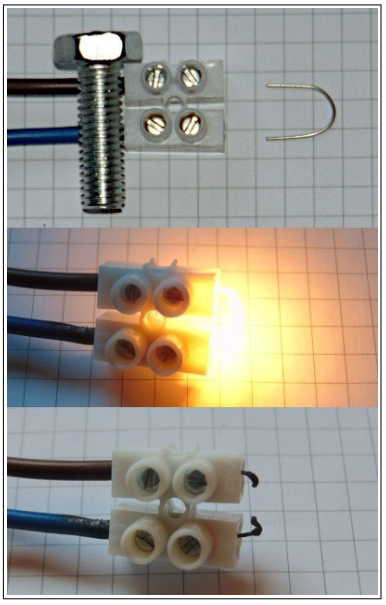
14.5 Glue down the switch



Roughen the bottom cap from inside, dot with a hot object or scratch 1.5 cm up from the bottom, one strip of interior up to the edge (facing the back of the switch). Drill a 4 mm hole into that strip.

Squeeze 1 cm of glue onto the bottom.
Place the switch in glue, hold until glue cools.
Inject extra glue at the back of the switch.

14.6 Make a bridgewire



Take 0.6 mm stainless steel (welding) wire and bend it into a U-shape around an M8 bolt. Keep it reasonably short - short bridgewires are fast and reliable. However, a slow bridgewire once allowed a fool to escape his mistake.

Other types of 0.6-0.8 mm wire may be suitable (even steel paperclips may work) but stainless steel is best - it has high electrical resistance and good heat tolerance. Nicrome could be better, but I haven't tested.

Ensure that the switch is off (otherwise you will burn your fingers). Install the bridgewire in the terminal block. Negative wire comes straight from battery "-", positive comes via the return wire from the switch. Now flip the switch.

- red glow, over 3 seconds: bad, low-current battery?
- yellow glow, 2 seconds: acceptable
- white glow, 1 second: ideal

14.6 Make thermite

Thermites are mixtures where two metals get oxidized / reduced exothermically. The best known thermite (rust + aluminum) produces molten iron, but is hard to ignite. Replacing rust with gypsum (calcium sulphate dihydrate) we can make calcium and aluminum react.

Gypsum thermite (by mass: 3 parts gypsum, 2 parts aluminum) ignites easier, from a bridgewire glowing white hot. It burns fast and blindingly bright. It bursts a

closed container with a bang. At normal pressure, it can ignite rust-aluminum thermite. Mixing by volume is influenced by particle size. If you must mix by volume: 1 part gypsum to 1.65 parts aluminum.

Dry gypsym in airtight packs is sold for construction and art. Aluminum powder is used to make paint. It can be self-made from a piece of aluminum by grinding, sawing or filing - but you get coarse powder, especially with sawing. The right stuff is called "serebryanka". I have tested with "AP1" serebryanka.

To mix thermite, get a plastic zip bag. Bags with double zip lines are better. Measure the powders, close the bag and vigorously shake for 30 seconds. Let it settle before opening - powder can float in air and contaminate your workplace.

14.7 Test ignition

Testing is important: a failed projectile tells a story about you.

Ignition is tested outdoors. Charge the battery, extend the wires with short disposable wires (you don't want to burn your arrow), make a batch of thermite into a small disposable vessel (3 tablespoons into the bottom of a paper cup). Put the terminal block with bridgewire into thermite, wear safety glasses, flip the switch.

Note the number of seconds it takes to ignite - if you drop a projectile, you have that many seconds to run. In my experience, loose termite ignites quick, dense thermite ignites slower. Dense thermite has more power, especially in a closed container - it almost explodes.

After testing, recharge the battery: remove the bridgewire, determine which wire is "+" and "-". Connect to your charger. If your charger only accepts 18650 cells, tape wires to a cell-shaped piece of wood and put the piece in the charger.

14.9 Make thermite charges

- take a 20 cm piece of 20 mm plastic cable pipe, scratch the interior of both ends (jigsaw blade, file)
- equip a terminal block with a bridgewire and 40 cm of wire
- push the terminal block into the cable pipe (trim with a knife if needed)
- place a toilet paper seal behind it, squeeze thermal glue on toilet paper (leave 0.5 cm unfilled)
- mix stiff epoxy (metal-filled epoxy?) and fill the last 0.5 cm, wait until solid
- turn the pipe around, choose a cleanable area, use a funnel and a spoon to pour thermite into it
- use a 5 ml spoon, start gently compacting after loading 35 ml
- don't push with substantially more force than the pencil's own weight
- thermite should become 2 x more compact (and powereful), I managed to load 50 ml
- put a toilet paper wad on thermite, squeeze thermal glue on the toilet paper, let it cool
- put epoxy on thermal glue
- make an anti-rip structure: run wires along the pipe first, cover with tape, bend back, cover again

14.9 Add toilet paper + plan your safety precautions

Please don't risk your life. Gypsum thermite burning in a closed container will burst the container. Without liquid fuel, that can wound you (typical: eyes, ears, neck + fingers), but not kill.

A thermite stick bursting a 50 cm x 40 mm pipe with liquid fuel causes thermobaric combustion. Sometimes, thermobaric explosion. All the fuel burns instantly, producing a shock wave. If someone is close, it can deafen, blind, throw the person, break lungs or other organs, knock them unconscious and set fire to them. The amount of energy released can make a motorcycle ride 10 km. **Taking precautions helps avoid this.**

Design and building:

- toilet paper is your friend, it won't release fluid to burn instantly
- have over 4 m of toilet paper in the payload compartment behind the thermite charge
- make shorter charges (not 20, but 10 cm), use even more toilet paper
- when possible, use slow burning liquids (e.g. not gasoline but oil)
- always test, burning fingers is much better than burning entirely

Dressing:

- dress like a cosmonaut, your clothes should be multi-layered and not flammable
- protect your head (e.g. earplugs + motorcycle helmet / earmuffs + protective glasses + hood)
- a fire extinguisher (at least 0.5 kg) should be on your belt or over your shoulder
- learn to use it blindly

Arming and filling:

- when arming a projectile with thermite, keep distance from people and fuel
- never put your face near anything
- only arm and fill outdoors, as late as feasible
- never transport filled projectiles where you can drop them
- never hit them against anything, or suddenly stop their forward motion
- a mild bump when loading into the barrel is allowed, because it stops backward motion

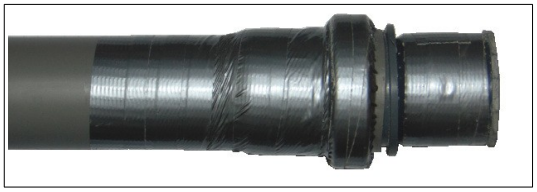
Assuming the worst:

- use a long wire trigger
- during teamwork, keep distance from gunners: to help them, you must be OK
- if you drop a projectile: run
- if the gunner runs, turn away, crouch down, cover your ears
- do not return before a quick analysis of risk
- projectiles can be poked with a long stick to determine stability (then retreat and wait)
- a styrofoam shield with a window may help disarm things safer
- consider draining the arrow and pulling with a string (get it away from fuel) or burning it

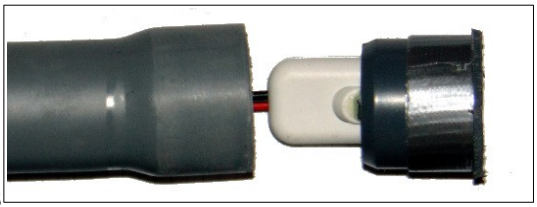
If it happens to you:

- take the extinguisher, pull the splint, turn it on yourself
- if you had 3 layers of clothing, only your outer clothes are burning, shed one layer
- as a last resort, rolling on ground reduces burns (your underside cannot burn)

14.10 Close and reinforce the tail

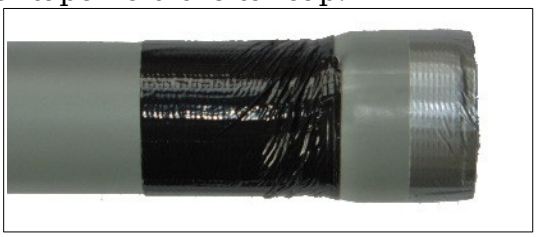


If the propellant charge is powerful, tails can break. If the tail contains a switch, losing the tail disables everything: we cannot afford losing it.



Top photo: if you use the double-cap (weak) tail, wrap the area of the seal compartment in many layers of narrow duct tape.

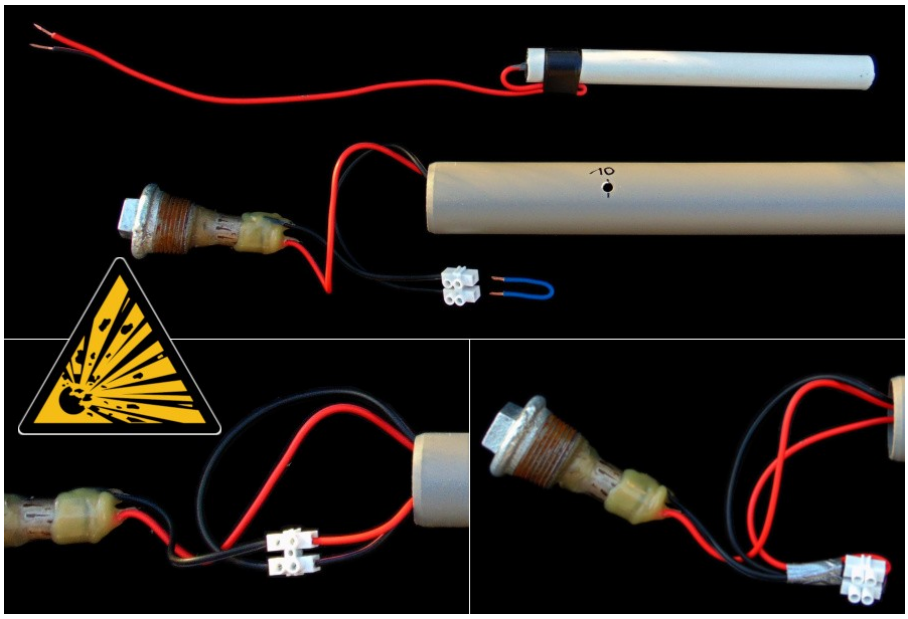
Bottom photos: if you use the single-cap (strong) tail, wrap duct tape around the cap until it nicely fits the tail. Reinforce the narrowing area. Let one loop of tape hold the tailcap.



14.11 Arm the arrow

Check list:

- outdoors?
- far from fuel?
- switch is off?
- eye and ear protection?
- did you load toilet paper?

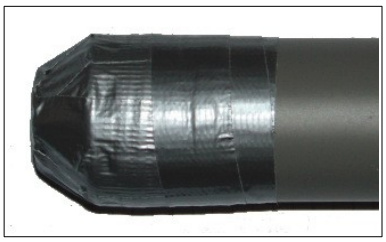


Do:

- with a thin U-shaped wire, touch the connector (bridgewire modules are good testing tools, producing light and heat without discharging the battery much): if you see sparks, the switch is ON

This check has saved me twice.

- slide the charge into the arrow
- with a small flat screw driver, connect one wire
- push the other wire into the hole, **walk away and count to 15**
- no bang? **fix screws securely**
- make an anti-rip structure for the terminal block (see photo)



- push the wiring into the arrow, reinstall the nose
- turning duct tape around the nose, fix the nose to the arrow
- make an aerodynamic cover from strips of tape over the nose
- if there is any risk of confusing armed / unarmed arrows, mark them

14.12 Fill with fuel, seal the fill hole

Check list:

- **outdoors**?
- **far from fuel?**
- **eye and ear protection?**
- **dressed like a cosmonaut**?
- **fire extinguisher**?

- can you carry projectiles from here to launch without risk of dropping?

Do:

- place the arrow on ground, nose slightly upwards
- turn the fill hole upwards, ensure it cannot roll
- take a funnel with a flexible hose (e.g. 0.5 m)
- the hose should have a narrow tip (e.g. construction glue nozzle)
- guide the tip into the fill hole
- take a bottle with the right amount of fuel (keep canisters away)
- add fuel into the funnel, check that fuel isn't spilling
- **unless you filled with water, the arrow is now deadly**
- remove the funnel, remove the bottle
- close the hole with 1..3 layers of tape

- if there is any risk of confusing filled / unfilled arrows, mark them

Note: it typically takes 1..3 seconds to from the switch flipping to a fireball (full battery, short bridgewire, warm weather). **If you drop the arrow, run!**

15. Propellant charges

The maximum charge this gun reliably tolerates is 558 ml of fully mixed acetylene at 0 C. This is equivalent to a "Sprite" bottle 100% full. Under some conditions, this charge breaks a gun: for example if you lay the gun with its back against hard ground (no sandbag). Sometimes it also breaks the bottle projectile "stem".

I propose a safe maximum of 500 ml at 0 C. This is practical since transparent 500 ml syringes are available for changing oil in cars. But people want to vandalize at different temperatures, so we need to convert this charge to volumes at different temperatures.

Using the ideal gas law "pV = nRT" *(p = pressure, V = volume, n = molecule count, R = gas constant, T = absolute temperature)* I propose that the following charges have the same power (in reality, they do not, because the mix ratio changes a little).

Volume at 0 C (273 K) = 500 ml -> volume at 10 C = 500 / 273 * (273 + 10) = 518 ml

Calculations show that for every +5 C difference from 0 C, you should add 9 ml of warmer gas, and for every -5 C difference, leave out 9 ml of colder gas.

0 C = 500 ml

5 C (278 K) = 509 ml	-5 C (268 K) = 490 ml
10 C (283 K) = 518 ml	-10 C (263 K) = 481 ml
15 C (288 K) = 527 ml	-15 C (258 K) = 472 ml
20 C (293 K) = 536 ml	-20 C (253 K) = 463 ml
25 C (298 K) = 545 ml	-25 C (248 K) = 454 ml
30 C (303 K) = 554 ml	-30 C (243 K) = 445 ml

Practise shows that this compensation is a bit weak - and hard to calculate when nervous.
For practical reasons, I suggest an easier formula:

0 C = 500 ml

5 C = 510 ml	-5 C = 490 ml
10 C = 520 ml	-10 C = 480 ml
15 C = 530 ml	-15 C = 470 ml
20 C = 540 ml	-20 C = 460 ml
25 C = 550 ml	-25 C = 450 ml
30 C = 560 ml	-30 C = 440 ml

16. Sights and aiming

This gun is full of compromises: it cannot be shot precisely. **It is suitable for vandalizing big things.**

With a laser sight, you can reliably hit an "average barn door" from 25 meters (aim 0.5 m higher). I have successfully hit a 60 x 120 cm styrofoam sheet from 30 meters with a 50% success rate. You can hit a building from 100 meters, but a specific part of the building: no way.

Weather also influences performance, especially wind, temperature and humidity. (If you need precision, I suggest remote controlled toys - wheeled machines are a cheap way of delivering bad stuff in quantity, and can be lifted over fences with a fishing pole.)

Photo: gun with two sight systems:

- for maximum-range shots, water level with rotating scale
- for direct shots, laser with 18650 cell in 32 mm cable pipe
- the cable pipe is glued and taped to the water level
- the water level is connected to the gun with double-sided tape + duct tape

17. Safety checklist

- If you don't know for sure, consider the barrel armed. Don't look into it. Never point at people. An empty sabot hitting the head can kill a person.

- Don't shoot a flechette or balls if you could miss your target. They fly far and could kill or wound someone down range.

- Take great care with electric arrows after filling. A premature explosion could kill a person.

- Always use a sandbag on hard surfaces, the gun needs soft support for the bottom cap.

- Never use oxygen with acetylene - explosion is guaranteed. With other fuels, **don't overdose oxygen** (preferably don't use oxygen at all). With oxygen, it is easy to produce a detonation, bursting the barrel. If you experiment with oxygen, move with tiny steps. Combustion does not scale in a nice linear manner.

- **Don't spill gasoline on yourself.** If you do, dry with paper towels, do not handle fire, remove the flammable clothes. If you must handle fire, dry them carefully from gasoline, rinse with water and squeeze dry.

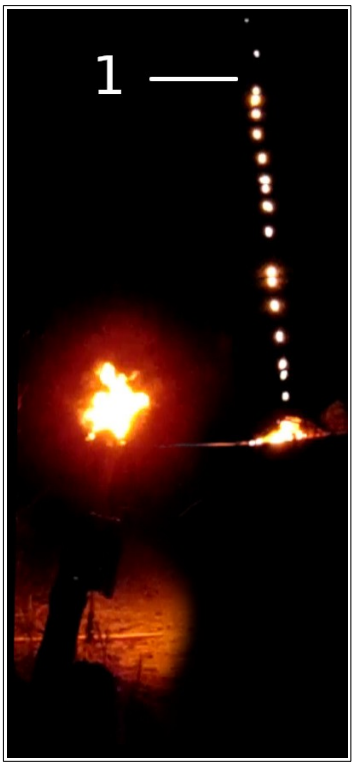
- **Have a fire extinguisher ready.** If you catch fire, enclosed protective glasses keep your vision and gloves protect your fingers - you can save yourself. If you can't use an extinguisher, roll on ground. If it doesn't help, try to discard outer clothing. I always shoot with a fire extinguisher ready. The smallest ones weigh only 500 grams - enough for personal protection. Water cools things, but doesn't extinguish gasoline. ABC powder works. Don't inhale it.

- If launching an electric projectile failed: take distance, consider the situation. Never throw the arrow out of the gun. Wear maximum protection while a comrade watches from safe distance with an extinguisher. Remove the arrow, move it aside. Remember: propellant is still in barrel. Maybe the piezo failed?

- If launching a manual projectile failed - it didn't fly out, but is burning - immediate risk of fire! Either leave and let your kit burn down (no evidence) or grab the gun and jerk it forward, ejecting the arrow. Retreat to safe distance with the gun. Remember: propellant is still in barrel! Maybe use a fire extinguisher to deal with the arrow (depends on circumstances).

- Roughen all surfaces which you glue. Common malfunctions happen when glue breaks. Typically at the worst moment.

18. Effects on targets



Plastic bottles

The bottle typically leaves burning, rarely in a blown-out state. When it slows, storm matches re-ignite it [1]. When it lands, it can shatter (fireball, no bang) or bounce (then it burns open in a few seconds)**.**

Glass bottles

The bottle typically leaves burning, rarely in a blown-out state. When it slows, storm matches re-ignite it. On hard surfaces, the bottle shatters (fireball, no bang). On soft surfaces, the bottle lands intact, fire may go out.

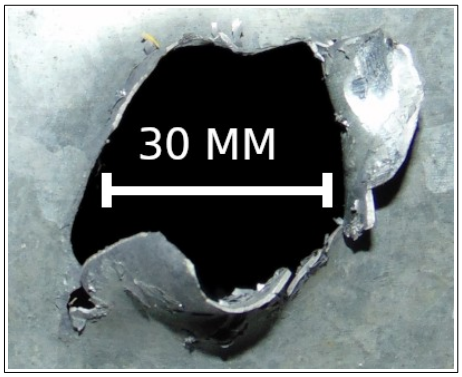
Manually ignited arrows

The rag slides back along the arrow, stops at the stopper bolt. The arrow leaves in nearly blown-out state. When it slows, storm matches re-ignite it. When impacting hard ground, it shatters, producing a fireball (no bang). When impacting soft ground, it digs into ground, expels fuel and burns.

Electric arrows

Arrows typically land after 5..8 s from launch. The igniter typically works 1..2 seconds. When the payload is an inert liquid, you get a loud flash-bang effect and liquid sprays out. When the payload is a combustible liquid, you may get a thermobaric combustion or explosion (very loud bang). Other payloads were not studied.

Flechettes



When tested against 1.2 mm steel with a charge of 558 ml C2H2, all flechettes went through, ripping holes of ~40 mm with tail fins.

They went through even when hitting a target sideways, leaving an elongated hole of 70 mm. Hitting sideways may happen when the sabot breaks early and flight is too short.

With flechettes, this gun can puncture car fuel tanks and most parts of aircraft skin. It cannot puncture railway fuel cars (12 mm steel) and always fails against armor. What thickness of steel stops it, depends on luck. I would guess 3..4 mm. A gun made specially for this (e.g. 1.5 m chamber, 1.5 m barrel, hardened flechettes) may break thicker steel, but **hasn't been tested.**

Pellets

When half a 50 mm pipe cap was poured full of pellets and a charge of 558 ml was used, with a laser sight it was possible to hit a styrofoam sheet sized 60 x 120 cm from a

distance of 30 m, aiming 0.5 m above it. Pellets did **not** scatter well during this distance. The sabot followed them and broke the sheet into 2 pieces.

The target was 10 cm thick and made of blue styrofoam (strong variety), 4.5 mm pellets were stopped by the sheet, 9.5 mm pellets went through (they were stopped by 5 cm of soft wood).

19. Disarming and disposal

Never pull the endcap from an armed 32 mm electrical arrow with the rubber seal present: pulling flips their switch!

For electric arrows: allow plentiful time, plan your activity:

- wear eye and ear protection
- dress thick, wear non-burning gloves (blacksmith's gloves protect, but make you too clumsy)
- cover as much as possible of your face and neck, I would consider a motorcycle helmet (and earplugs)
- have a helper stand by with a fire extinquisher, or an extinguisher on your belt

Ideas:

- poke the arrow once with a long stick to ensure it's stable
- push holes into tape, let the fuel drain out
- with a piece of rope, pull the arrow away from fuel before other work

If you tested a projectile with a thermite charge, or a projectile filled with something flammable, but it didn't work, sometimes the question comes - should you try to disarm? If the pipe was filled with water, recovering may be smart. If the pipe was filled with something very nasty - maybe you should burn it, if landscape allows?

20. Alternative propellants

Electrolysis gas: powerless.

Propane / butane with air: unreliable, combustible range is narrow, mix timing is hard.

MAPP with air: unreliable, MAPP is not standardized, combustible range is narrow, mix timing is hard.

MAPP with oxygen (1:3): effective with 1 meter chambers and 1.3 L fill volume. Allows fast shooting without ventilating the chamber. Could burst the chamber. Untested with smaller chambers. Mix times need research. Buying even small cylinders of oxygen is impractical - they cost too much to throw away.

MAPP with electrolysis gas at ~1:10 by volume: effective, somewhat too powerful with 1-meter chambers and 1.3 L fill volume (1200 ml of electrolysis gas + 100 ml of MAPP). Really violent with small chambers.

Aged electrolysis gas kept in a condom bottle for some hours: oxygen remains, but hydrogen (the smallest molecule) has partly escaped through latex. Cheaper way of replicating a 1:3 oxygen:MAPP mixture.

21. Electrolysis

If state limits access to carbide, I would use a propellant of propane/butane with electrolysis gas.

Photo: electrolysis cell doing work 5A @ 7V (moisture filter on right)

Materials:

- protective glasses and nitrile gloves
- plastic box with a sealing lid
- about 7 meters of 1 mm welding wire (stainless steel A4 or 316 recommended)
- a DC power supply (ideally: adjustable from 5..12 V, capable of giving 10 amps)
- flexible hose, small diameter (e.g. 8 mm)
- 32 mm pipe joiner as the "riser pipe", 1 x 32 mm pipe cap for the exit cap
- 32 mm pipe joiner for the moisture filter, 2 x 32 mm pipe caps for filter caps
- toilet paper, motor silicone, thermal glue, lamp wire, soldering iron, screw terminals

To use the electrolyser for a few times, any stainess wire is OK. To use it for long, good wire is needed. To my understanding, grade "A4" or "316" is the best. This kind of welding wire is used for boats and brewing instruments.

With some electrode lengths, a PC power supply **may** work, but is not adjustable, it simply supplies 5V and 12V power, for which you need to adjust electrode lengths (12V: make shorter electrodes, 5V: make longer electrodes). If you go with a PC power supply, to activate an ATX PSU without a mainboard, short the green line (probably fourth from the left in the upper row, if you look into the connector and the clamp is upward) to a black ground wire right of it.

Consumables:

- distilled water (battery water for cars is distilled)
- drain cleaner: granules of NaOH (liquid NaOH works, but we don't know the concentration)

Safety:

- wear protective glasses, gloves, multi-layer long-sleeved garments
- NaOH causes serious chemical burns, if you contact it, flush with water
- **never let your electrolysis cell short-circuit**, sparks could make H2 + O2 explode
- **always fill your electrolysis cell to a high level**, reducing the amount of explosive gas in the cell
- **the current is influenced by temperature**, thermal run-away is possible, monitor your cell
- **never use thermal glue on electrodes**, hot electrodes will melt themselves free
- check the temperature of the electrodes from outside the box with a finger, you should be able to touch them for a few seconds

Theory:

- current is influenced by the surface area of the electrodes: more stainless wire is better
- longer electrodes work with lower voltage, short electrodes need higher voltage
- during work, the surface area of the electrodes gets bigger from corrosion
- plus = O2, minus = H2, the oxygen-making electrode corrodes faster
- if you want to quickly reach normal electrode wear, switch polarity
- current is influenced by the number of Na+ and OH- ions in the water, but you can't do wonders

Construction:

- **sand and dot the plastic** everywhere you glue it
- glue hoses into caps with thermal glue from the inside, glue depth 1.5 cm
- make a hole for the riser pipe (less than pipe diameter) into the lid with a hole saw or hot metal
- make electrode holes (1 mm) into one end of the box
- measure stainless wire, fold it, tie the wire into a bunch with short pieces of the same wire
(tie from 3 points, don't use plastic cable ties, they melt)
- use pincers or gentle hammering to compress the bent ends, so wire is not tense
- sand the wire where it passes through plastic
- place electrodes in box, **make a "stress relief bend"** (they expand and contract with heat, longer bends are better at relieving stress)
- fix temporarily with tape, glue with **metal-epoxy from the outside, motor silicone from inside**
- fix the riser pipe with thermal glue (silicone cannot hold it, I tested)
- wait 72 hours for silicone to cure, keep the box open, it needs air and moisture
- install toilet paper in the filter capsule
- grease and **gently** insert the top connector into the riser pipe

Power supply:

I use an adjustable-output DC/DC converter. With the electrolyser depicted above, with electrode lengths depicted above (6.5 m total, 3.25 m plus, 3.25 m minus) applying a voltage of 7 V, I get a current of 5 A (power 7 x 5 = 35 W), and electrode passthroughs get hot enough to burn fingers (cannot be held over 10 seconds).

Results:

With my cell, producing 1.3 liters takes 30 minutes. This is the maximum power you should try to achieve with 1 mm electrodes. If you overpower the cell, electrodes can melt themselves free.

Use 50 ml of NaOH granules per 2 liters of distilled water. If you use KOH, it will work but quantities differ. Solubility for NaOH is theoretically super high (418 g/L at 0 C, 1000 g/L at 25 C). Avoid making such strong solutions - it makes the liquid more dangerous.

Photo: top view of electrolysis cell, silicone needs 72 hours to harden.

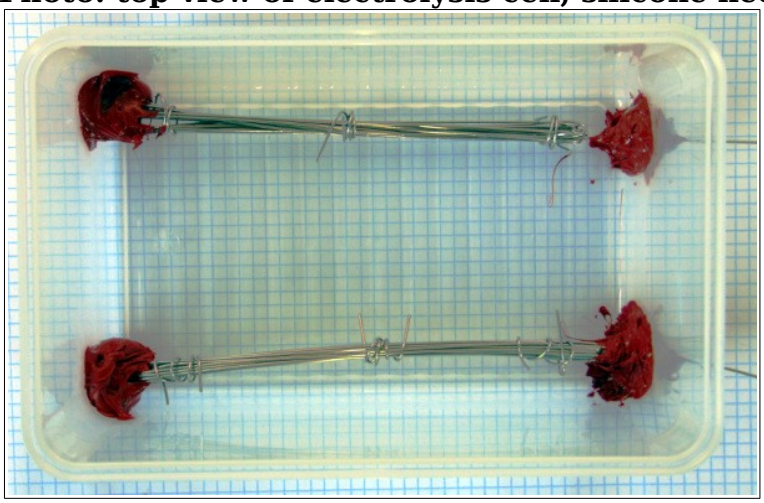


Photo: electrode pass-through, twist in wire reduces thermal expansion (should be longer).

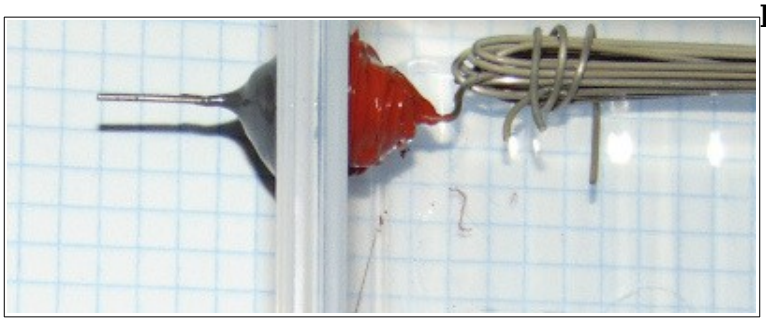
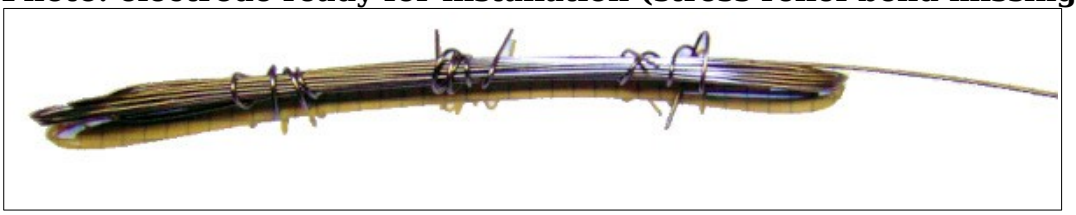


Photo: riser pipe (prevents bubbles from entering the hose), note the dotted surfaces.

Photo: electrode ready for installation (stress relief bend missing)



22. List of alternative designs

- 1-meter guns are possible
- natural laws don't forbid very long guns, but chamber pressures get big
- it is possible to make recoilless guns with ejectable ballast
- 6 pcs of 32 mm pipe around a 32 mm pipe: a very efficient but **fragile** ring stabilizer
- two symmetrically placed ribbons, 50 cm each: an aerodynamically **inefficient** stabilizer

23. Ballistic data

Theoretically, the enercy density of acetylene is 11.8 kJ / g, and the density is 1.17 g / L. Thus, 1 L of acetylene holds 13.8 kJ of energy. A typical charge of 0.5 L contains half of that - approximately 6.9 kJ.

For comparison, the upper limit of the energy density of gunpowder is around 11.3 kJ / g. The maximum capacity of a 7.62 mm rifle round is 3.32 g, making the energy 37.5 kJ - much stronger.

Physics of combustion and subcaliber shooting prevent a simple comparison. A rifle spends most of its energy creating the muzzle flash and bang. A potato gun is more efficient, but some energy stays in the sabot. If the projectile is heavy (an arrow), it gets a bigger percentage of energy. If the projectile is light (pellets), the sabot keeps most energy.

Angles are in degrees, time in seconds, distance in meters.

Proj = projectile number
Acet = acetylene dose
Temp = temperature C
Ang = angle degrees
Mix = mix time, seconds
Fli = flight time, seconds
D = distance, meters

Projectiles are as follows: 1 - electric arrow, 2 - manual arrow, 3 - glass bottle, 4 - plastic bottle

Proj	Acet	Temp	Ang	Mix	Fli	D